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CTION OF TRAFFIC CONTROLS FOR SEVERE WEATHER CONDITIONS

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Offices of Research & Development

Washington, D. C. 20590

Foreword

This report provides a methodology for the selection of traffic controls to reduce the hazards created by severe weather conditions to travel on limited access highways. Although it is by necessity an elementary treatment, it should be useful to maintenance or traffic engineers in considering special traffic controls for severe weather conditions.

The report presents the results of a study entitled "Guidelines for Employing Special Traffic Control Measures Under Extreme Adverse Environmental Conditions." The study was conducted for the Federal Highway Administration, Office of Research, Washington, D.C., under Contract DOT-FH-11-8779. The final report covers the entire period of research.

Sufficient copies of the report are being distributed to provide one copy to each FHWA Regional office.

D. Solomon

for Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

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16. Abstract

This manual provides guidelines for the selection of traffic controls to reduce the hazards created by severe weather conditions to travel on limited-access highways. The guidelines emphasize the need to determine the severity of the hazard and to estimate the level of investment that is warranted prior to implementation of a control to counter the hazard. The criteria to be applied to assure that the basic functions of traffic control are achieved are provided as an aid in the selection or design of traffic control measures. Analytical techniques are described in procedural format, along with worksheets, for use by traffic engineers in quantifying the extent of the accident or delay hazard created by extreme weather conditions. A methodology for selection of the most appropriate traffic control is presented based on estimating the level of effectiveness that must be achieved by a control in order to be cost effective.

Summary descriptions of traffic controls implemented by the States under various adverse weather conditions, and a comprehensive annotated bibliography are provided in appendices to the report.

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Metric Conversion

Several customary units appear in the appendixes to this report.

To convert	To	
ft	m	Multiply by .3048
mi/h	km/h	Multiply by 1.6
^{o}F	^{o}C	Subtract 32 and multiply by 5/9
lb	kg	Multiply by .45

The pound is a measure of force and the kilogram is a measure of mass. Mass and weight are not equivalent. For an object weighed under normal gravitational conditions, however, the above relationship may be used.

I. INTRODUCTION

Adverse weather conditions, particularly at extreme levels of severity, pose a unique set of hazards to highway travel. The hazards created by adverse environmental conditions are generally those associated with reduced visibility, reduced or loss of vehicle control, and interrupted traffic flow. The environmental conditions most commonly contributing to these hazards include:

- dense fog, smoke, or dust
- snow and ice conditions
- preferential icing (bridge decks)
- high winds
- flooding
- mudslides.

Revisions to current vehicle or highway designs are not likely to be cost effective in reducing the hazards created by these conditions. However, application of appropriate traffic control measures can contribute significantly toward accomplishing the objective of decreasing both the frequency and severity of highway accidents, and the excessive travel delays arising primarily as a result of these conditions.

It is anticipated that traffic controls will become increasingly important as countermeasures to reduce the hazards encountered in highway travel. The current emphasis in highway safety on roadside improvements at hazardous locations is likely to decline as progress is made in reducing the accident rates associated with those conditions. Well planned and executed traffic controls, however, present an excellent opportunity to increase the nominal capacity of highways by maintaining traffic flow at reduced accident levels during periods of adverse environmental activated conditions. Reliable detector-activated and other electro-mechanical traffic control devices can also provide a cost effective approach to upgrading the design or safety standards of existing roadways and can reduce or defer the demand on the road construction budget.

Selection and application of appropriate traffic control measures to accomplish these objectives are complicated considerably by the varied nature of the hazardous conditions. Adverse environmental conditions may exist as either a general condition, e.g. snow, or as a site-specific condition as in the case of preferential icing of bridge decks. For any given environmental condition such as fog, there may be considerable variance in the severity and duration of the resulting hazard.

There is a comparable diversity in the type of traffic control measures that might be applied to minimize the hazards created by adverse environmental conditions. These controls may range, for example, from a permanently displayed sign warning of a potential hazard, to a logistic approach such as organization of motorists into convoys led by enforcement personnel through the affected area.

The effectiveness of these controls in reducing the potential hazard will also vary considerably depending upon the nature of the control measure and the motorist's perception of the severity and immediacy of the hazard. While virtually any desired level of traffic control, including road closure, can be imposed to counter a hazardous condition, there are costs associated with these measures: both the monetary costs of implementation and operations and the economic costs of increased travel time. Selection of an appropriate special traffic control measure, therefore, requires consideration of the probable effectiveness of a measure in reducing the frequency or severity of accidents and maintaining traffic flow. Final selection should be based on an analysis of the cost of implementing each alternate control measures with the anticipated level of effectiveness of each measure.

Traditionally, the selection of highway accident countermeasures has been hampered by the limited availability and reliability of accident data, particularly that related to the specific location, cause, and severity of the accident. The shortcomings associated with the data have made it difficult to determine the most appropriate countermeasure action, and even more difficult to evaluate the effectiveness of a countermeasure, once implemented, in reducing accidents. Although some progress is being made in standardizing and improving the validity of accident data, the low quality of the available data will continue to be a problem in evaluation of countermeasures and application of appropriate cost methodologies as part of the selection process for the near future.

Selection of traffic controls to minimize potential delays in traffic flow have been hampered by inadequate data on the frequency of occurence of these events and the lack of reliable estimates of the costs to highway users attributable to the delay.

Recognizing the problems faced by traffic engineers in the development and justification of traffic control measures, this manual was developed to furnish a methodology that provides a reasonable basis for selection of measures to counter the specific hazards created by extreme adverse environmental conditions.

1. OBJECTIVES OF THE MANUAL

This manual is intended to serve two major objectives. The first objective of the manual is to describe a methodology for estimating the nature and level of the hazard created by adverse environmental conditions. The methodology is intended to be modular in terms of its ability to handle data at various levels of detail. Its basic purpose is to provide the traffic engineer with a sound basis for determining the extent of the hazard created by various adverse environmental conditions, and then estimating the level of benefits likely to accrue through application of a traffic control measure.

The second objective of the manual is to provide a technique for selection of cost effective traffic control measures within the context of the overall requirement of the highway safety program. This objective addresses a frequently encountered problem: the one of selecting those traffic control measures or highway improvements that will result in a maximum reduction in hazards to highway travel within the level of funds available for that purpose.

2. SCOPE OF GUIDELINES

The scope of the guidelines provided in this manual are limited to traffic controls that are applicable to travel on limited access highways under extreme adverse environmental conditions. Although these guidelines may encompass a wide range of climatic conditions under that definition, the nature of the hazards created by any of these conditions is limited to those associated with significant reductions in or loss of:

- driver visibility
- vehicle control
- vehicle mobility

The guidelines are intended to be of use in the selection of either a traffic control strategy or a specific control measure, and the terms are used interchangeably throughout the manual. For purposes of definition, however, it should be pointed out that a control strategy describes the basic action selected to minimize a hazard (e.g., diverting a class of vehicles as opposed to route closure). Implementation of a traffic control strategy may involve initiation of several traffic control measures such as speed reduction and route diversion.

The control measures covered by the guidelines, therefore, may be either of an electro-mechanical nature, such as detector-activated message signs, or of a procedural (logistical) nature, such as those involving route diversion or closure. While the guidelines should be of assistance in the development of a traffic control strategy, they are not intended to provide a detailed description of implementation procedures. Because of the differences in site conditions, agency responsibilities and authorities, and availability of resources, control procedures generally are not readily transferable in an unaltered form. However, Appendix A to this manual does provide a summary description of selected control measures currently in use which may be of assistance in the development of procedures.

3. ORGANIZATION OF THE MANUAL

Chapter II describes the major components of the problem confronting the traffic engineer in determining the nature and severity of the highway hazard created by adverse environmental conditions, and in selecting the appropriate traffic control measure to apply in reducing the hazard. Chapter III provides a description of the procedures used to identify the extent of the hazard created by environmental conditions. In Chapter IV, the detailed methodologies for selecting traffic control measures are presented in a procedural handbook format. The determination of the benefits of traffic controls and the process of selecting appropriate controls can be made much more reliably with the accumulation of data on the effectiveness of individual control measures. Chapter V describes the basic data requirements and analytical procedures for determining the effectiveness of implemented controls for future use in those efforts.

The Appendices to the manual are devoted primarily to providing additional detail in support of the methodologies, and furnishing background material that may be useful in the development of appropriate traffic control strategies. Appendix A provides summary descriptions of tested or ongoing control measures for reference in developing specific strategies. A bibliography of materials related to traffic control measures and environmental conditions is contained in Appendix B.

II. TRAFFIC CONTROL STRATEGY SELECTION CONSIDERATIONS

In this chapter we identify the major factors to be considered in developing a traffic control strategy to counter the hazardous situation created by extreme adverse environmental conditions. The chapter focuses on the constraints under which the traffic engineer must operate, and provides the basis for understanding the approaches taken in the development of the methodologies described in the remainder of this manual.

1. ENVIRONMENTAL CONDITION CHARACTERISTICS

There are a number of adverse environmental conditions that may create hazards to highway travel. While most may be categorized as hazards associated with highway travel under adverse weather conditions, some, like mudslides, may occur during clear weather conditions following periods of adverse weather. Environmental conditions creating travel hazards include:

- Snow and Ice
- Fog
- Dust and Sand Storms
- Flooding
- Ice on Bridge Decks
- Mudslides
- High Winds.

As these conditions are all weather-related, they vary considerably in the extent and duration of their effect on highway users. Severe snow storms, for example, can affect a major portion of the highway system and a large number of highway users for extended periods of time. In contrast, preferential icing of bridge decks is a very localized hazard of short duration, which occurs most often during the hours of light traffic volume. The extent and duration of other adverse environmental conditions fall generally within the range established by these two extremes. Fog, for example, may occur as a general condition over several miles of

highway, or it may be localized at specific sites. Dust storms may exhibit a similar variance in the length of highway affected, and as in the case of mudslides, may be confined to areas having specific topographical characteristics.

Reduced visibility or loss of control of a vehicle as a result of one of these environmental conditions presents obvious hazards to the highway user and may result in collision with another vehicle or a fixed object off the travelled way. A motorist who loses mobility, such as might occur in heavy snow or in flood conditions, runs the risk of being stranded or of being hit by another vehicle, and may impede or even block traffic flow. The resulting interruption in traffic flow creates still another hazard to the highway user.

Countering the effects of extreme adverse environmental conditions generally cannot be accomplished through the use of routine traffic control measures. It requires developing new approaches or supplementing existing controls with additional measures to assure highway user compliance.

2. CONTROL MEASURE CHARACTERISTICS

In considering the application of a traffic control measure to reduce the environment-related hazards to highway use, the traffic engineer has a relatively wide selection to choose from. Some of the traffic control devices or measures that have been applied to adverse weather conditions include:

- Fixed signs
  - Temporary display
  - Permanent display
- Variable message signs
  - Manually activated
  - Remote and sensor activated
- Warning lights
  - Manually activated

- Remote and sensor activated

. Roadside transmitters

. Convoying of motorists

. Route diversion

- Restricted lane control

- Closure

- Selective diversion of vehicles by class or equipment.

Selection of one of these controls as the most appropriate for a given hazard requires consideration of both the probable effectiveness of the control and cost of implementation relative to the level of benefits to be derived.

In addition to these basic considerations, there are other factors that influence the type of traffic control measures selected, such as:

. Location of hazardous condition, i.e., site-specific versus general conditions

. Predictability of condition

. Variance in motorist response to control measures.

Each of these factors is discussed separately in the following sections.

(1) Location of Hazardous Condition

The selection of a traffic control measure is governed generally by the locational characteristics of the environmental hazard-- i.e., whether it is site-specific or affects a general area of highway. When the hazard is confined to a specific location as in the case of bridge deck subject to icing, fog pocket, or a mudslide area, it is, the common practice to rely on fixed warning signs. These signs may achieve the desired response among at least some of the motorists because the sign is close to the area of perceived hazard. Permanently displayed signs in general, however, are of minimal effectiveness in site-specific

situations. Variable message signs or flashing lights affixed to signs, either manually or remotely activated, can be effective if the message is regarded as reliable by motorists. In considering warning sign installation at specific hazardous locations, therefore, the engineer should assure that:

- The advisory can be provided in a timely fashion for the period that the hazard exists

- The advisory informs the motorist of the appropriate action to take to counter the hazard.

If these criteria can be met, advisory signing can be reasonably effective as a traffic control measure in reducing the hazards created by environmental conditions at specific sites.

The implementation of traffic controls in response to general conditions of environmental extremes, such as snow or fog, poses a more complex problem. Traffic control strategies for these conditions commonly require logistical measures such as route closure or chain control stations in order to reduce the hazard to travel. Initiation of these traffic control procedures may be triggered either by surveillance reports or through reliance on predicted conditions. Signing may supplement these traffic control measures, but in most instances adequate response to widespread adverse environmental conditions will require mobilization of transportation and enforcement agency personnel and equipment for management of traffic flow during the period the hazard exists. Scheduling and deployment of personnel and equipment should be accomplished in accordance with previously established procedures.

(2) Predictability of Condition

The type of traffic control measure selected for countering environmental conditions affecting travel, and the degree of motorist responsiveness that is attainable in implementing the control, are influenced by the predictability of the condition. Many of the adverse environmental conditions encountered by highway users are predictable to at least the same level of accuracy achieved in general weather forecasts. If the onset of the condition were the only criteria for implementation of the traffic control, the

response time for implementation and the false alarm rate could be maintained at acceptable levels. However, the severity of the condition, which is much more difficult to predict, is very often the deciding factor in electing whether to implement a control measure, and, if so, at what level of control.

The predictability of a condition, therefore, can significantly affect the timeliness of a traffic control measure and its effectiveness in reducing the hazard. Some approaches that have been applied to either predict the need for, or to increase the timeliness of control implementation include:

- Increased surveillance of historically troublesome locations
- Arrangement for specific area weather watches provided by local or national weather services
- Devices to detect presence of a condition at a specific site.

These approaches, when combined with established criteria for implementation of controls at various levels of severity can significantly reduce the response time and thereby improve the effectiveness of special traffic controls.

(3) Variance in Motorist Response to Control

The final test of the overall effectiveness of any traffic control is the degree of success that it achieves in reducing the number of accidents or the travel delays associated with adverse environmental conditions. The success of a traffic control measure is thus dependent upon its effectiveness in producing the desired action by motorists, which will minimize the hazard confronting them.

Traffic controls are not equally effective in producing a desired response by motorists. There is even likely to be a difference in motorist response to a given traffic control measure under different conditions or at different locations. The level of response by motorists that can be achieved by a traffic control depends upon whether the control requires voluntary or involuntary action by the highway users. Some examples of controls that fall into these two categories of control are described below:

. Voluntary

- Travel and weather condition radio advisories
- Warning signs or other roadside advisories

. Involuntary

- Convoying of motorists
- Route closure and diversion
- Highway user restrictions
  .. Vehicle class
  .. Vehicle equipment.

Traffic controls requiring voluntary compliance by the motorist are not sufficiently effective under most circumstances to be regarded as appropriate measures for dealing with extreme adverse environmental conditions.

Traffic controls which rely on enforced compliance are highly effective in achieving the desired response or action by highway users. However, implementation of involuntary traffic control measures, such as convoying of motorists, requires considerable preplanning to assure rapid response and effective assignment of personnel and equipment. The cost of this category of controls can be high, both in terms of actual operating costs and the cost associated with diverting resources from other activities.

Very little data exists at present on the level of effectiveness achieved by various control actions during periods of adverse environmental conditions. The effectiveness of the control in obtaining the desired motorist response, and, therefore, the overall effectiveness of the control are dependent to a large extent upon the approach taken to accomplish each of the major control functions.

3. CONTROL MEASURE FUNCTIONS

In the development of traffic controls for countering the hazard of adverse environmental conditions, the engineer

should give adequate consideration to four major functions associated with implementation of those controls. The engineer should assure that each proposed control includes provision for:

- Detection of the hazardous condition
- Notification of the hazard
- Control of traffic to reduce hazard
- Removal of traffic control.

Each of these activities is essential to implementation of effective traffic controls, and should be the subject of separate analysis in the development of a specific control strategy.

(1) Detection of the Hazardous Condition

Detection of the adverse environmental condition creating a hazard to highway travel is the first step in implementation of a special traffic control. It is also the most important in achieving the timely response necessary for effective control measures. Detection of adverse environmental conditions is usually provided or confirmed by a human observer. Detection of potentially hazardous conditions, however, should not be left to chance and can be augmented by:

- Prediction or forecasting
- Electro-mechanical sensing devices
- Special surveillance activities.

Some weather conditions and related hazards to highway travel can be predicted with a reasonable level of confidence. National and localized weather forecasting services are available that can be useful in providing advance warning of the need to implement special traffic controls. When the hazard is one that occurs at specific sites under certain weather conditions, arrangements can usually be made for increased weather reporting or monitoring at these locations.

There has been considerable testing of and experience gained with the use of sensors to detect

specific environmental conditions, particularly bridge deck icing and fog. These detection systems can offer a number of advantages, including the timeliness of response they can provide to hazards and their applicability to remote installation. However, the experience to date with these systems indicate that additional research and further improvement are necessary to improve the reliability of these systems. Many of the systems which relied on sensors have been abandoned after a year or two of testing because of unacceptably high false alarm rates. The experience of the agencies using detector-activated systems generally has been that the effectiveness of these systems is highly dependent upon the credibility that motorists assign to the warning message. Once a system develops a history of false alarms, highway users tend to ignore the warning even under hazardous conditions.

Although remote detection of hazardous conditions is not generally reliable enough for operating warning signs, in some cases it may be helpful in alerting highway department personnel of a hazardous condition. In these cases, increased surveillance by highway department personnel or the police can offset the present shortcomings of remote detection systems.

(2) Notification of the Hazard

Notification of persons or agencies affected by a critical environmental condition involves transmission of information on three basic levels. First, the motorist must be notified. Second, the control agency (such as state police) must be contacted so that they can bring the necessary resources to bear on traffic control. Finally, support agencies (such as the highway department) must be contacted so that they can provide the additional resources necessary for corrective action. Corrective action or support efforts might include such activities as plowing, sanding, alternate routing, staging, and traffic control. While the procedures and responsibilities of the various agencies for dealing with adverse environmental conditions may not always be clearly defined, adequate communication links generally exist between the highway police organizations and the State or independent highway agencies. Improvements made in this area are likely to come from preplanning, definitive assignment of responsibility under varying tactical strategies, and efficient use of existing communications equipment.

Considerable research efforts have been expended in the area of highway user information systems. The most commonly encountered motorist information device is, of course, the fixed message sign which may be permanently displayed or uncovered when conditions warrant. Attention may be directed to fixed message signs, when appropriate, by manually or automatically activated flashing lights. A recently developed information device, but one having increasingly widespread application, is the changeable message sign, which is generally used to vary speed limits and provide advice on traffic or weather conditions ahead.

Studies indicate that upwards of 85% of the highway users listen to the radio while traveling which indicates that traffic advisories broadcast by commercial radio stations or low power roadside transmitters may be an effective way of informing the highway user of travel restrictions.

(3) Response/Control of Traffic

Several types of motorist response are desired following notification -- all are directed toward protecting the life and property of the motoring public and minimizing the impact of critical environmental conditions on normal traffic flow. The response mode of the highway user may be either voluntary or controlled. An example of a voluntary control would be a sign or individual notifying the motorist of the appropriate action required to reduce the hazard to continued travel (chains, speed limit, use lights, no stopping, etc). A controlled response is one effected by force of law; it involves continuing presence of authority to assure the required response. Examples of this approach include lane control and flagmen, convoys led by state personnel, and use of barricades for diverting or holding traffic until the criticality of the condition is reduced.

Obtaining the desired response of motorists is usually dependent upon a variety of factors, including:

. Message credibility

. Nature of the condition and perception of danger

. Nature of trip (local, commute, transient, etc.)

- Authority perceived
- Alternate route familiarity
- Response of other motorists.

State agency response is also required to support the logistical actions required by the condition. Site management (usually from the enforcement agency) and condition abatement resources must be applied to reduce the period of delay or interruption in traffic flow.

Unfortunately, most efforts to respond effectively in countering the hazards created by extreme environmental conditions are designed and implemented in an uncoordinated fashion following discovery of the condition. In the absence of early detection and/or preplanning, the response of public agencies may be too late to avoid traffic accidents or other interruptions in traffic flow. The cost of implementing these traffic controls may also be high because of the inefficiencies incurred when reacting in a crisis mode.

Properly planned and executed traffic control programs, however, can be most effective in minimizing the hazards created by environmental conditions. Despite the difficulties that are frequently encountered in coordinating interagency or multi-jurisdictional efforts, development of formal agreements which assign responsibilities and describe the implementation procedures is essential to effective management of special traffic control programs.

(4) Removal of Traffic Control

The removal of a control measure to restore traffic flow to normal levels following the abatement of adverse environmental conditions, like the imposition of traffic controls, is generally a problem of logistics and interagency coordination. Restoration procedures include changes, repair, or abatement operations, neutralization of notification mechanisms, and removal of traffic control measures. These steps should be performed as quickly and as efficiently as possible to minimize the economic loss attributable to restricted traffic flow. In most States, these operations are performed on a somewhat ad hoc basis, and considerable time is lost in dealing with isolated situations or unusual adverse environmental conditions.

Incidents necessitating rerouting of traffic may involve several different jurisdictions and frequently result in excessive delays in both initiating and removing traffic controls.

To minimize the costs of delay associated with restricted travel, the procedures which are developed for initiation of controls should also clearly delineate the responsibilities and coordinating activities of the agencies concerned with resumption of normal flow, following periods of extreme adverse environmental conditions.

4. ESTABLISHING OBJECTIVES OF TRAFFIC CONTROLS

The principal objectives of special traffic controls are to reduce either the frequency and severity of accidents attributed to extreme adverse environmental conditions, or the delay time that may be incurred by motorists in encountering an adverse weather condition. Within that overall objective there exists a range of traffic control objectives that might be established to reduce the possibility of weather induced accidents or delays. However, traffic controls cannot be regarded as equally effective in achieving the desired reduction in accident or delay severity. Nor are all traffic controls equally effective in achieving the desired control objective. For example, a traffic control which is directed at reducing traffic speed through an affected area may not be as effective in reducing the frequency of accidents as a control which relies on route diversion. Similarly, a traffic control which relies on changeable message signs to achieve a speed reduction will not be as effective as one involving convoying of motorists by law enforcement personnel.

Effectively countering the hazards to highway travel created by adverse environmental conditions generally requires application of traffic controls which are non-routine in nature. Their effectiveness is dependent to a considerable degree upon sizeable investments in operating personnel time or funds or both. The amount of investment in the implementation of these special traffic controls can be quite large. At present, however, there are no generally accepted guidelines on the type of controls or level of investment that are appropriate for reducing the hazards to travel during conditions of extreme adverse weather. The guidelines and procedures described in this manual can be of assistance in making that determination, but even they are limited by the scarcity of reliable data on the cost and effectiveness of existing controls.

The basic approach to defining the extent of the need for traffic controls in extreme adverse environmental conditions can be sumamrized in the following activities:

- Determine exposure
- Define how control will reduce incidents
- Estimate payoff
- Determine probability of implementation

(1) Determine Exposure

Each analysis of the potentially hazardous conditions for which a special traffic control appears warranted should start with a determination of the nature and level of motorist exposure.

Exposure levels should be examined in terms of:

- Vehicle classes
- Driver classes
- Frequency of conditions
- Types and number of incidents which might be reduced by effective traffic control.

- Vehicle Class

The rate of exposure of vehicles, by class, to an adverse environmental condition can influence both the degree of severity of the hazard and the type of traffic control which is likely to be effective in reducing the hazard. Commercial vehicles, for example, because of their weight and visibility advantages may be effected less by heavy snowfall than private vehicles. Conversely, high profile vehicles such as tractor-trailers, motor homes, or private auto trailers may be more affected by high winds than private passenger vehicles.

The rate of exposure of each vehicle is a function of several factors including time of day, month of the year, and type of highway.

Ideally, the rate of exposure by vehicle class should be determined by actual traffic count data, if not during the periods of adverse conditions, at least during comparable periods in terms of time of day or day of the week. Adjustments should be made to traffic volume estimates, either by class or overall, to account for the decline in traffic volume during periods of adverse weather. Most of this information is not routinely collected by the state and therefore will require special traffic counts or manipulation of other relevant data to provide reliable estimates.

Based upon the exposure levels of various vehicles classes, several alternative approaches to traffic control may be suggested. As one alternative that class of vehicle for which the hazard is not severe might be directed to an alternate primary or secondary route. If division of one or more vehicle classes is infeasible, the frequency or severity of incidents may still be reduced by confining comparable vehicle classes to designated lanes through the affected area.

- Driver Class

There is considerable variance in the response of various classes of drivers to both a hazardous condition and the traffic control that may be implemented to counter a hazard created by adverse environmental conditions.

Commuter drivers, because of their greater familarity with a highway segment, are likely to react quite differently as a class to an adverse weather condition or advisory than a through traveller. These differences, and the impact of time of day on the type of driver exposed should be considered in the selection or development of appropriate traffic controls.

- Frequency of Conditions

  The frequency with which extreme adverse conditions occur effects not only the rate at which accident or delay incidents occur, but also the level of investment that may be warranted in a traffic control measure. Despite the sensationalism effects of chain collision or multi-vehicle accidents in dense fog conditions, the low frequency of occurence of these conditions over the same highway segment, or the small percentage of accidents attributable to those conditions relative to other causes may not provide sufficient justification for traffic control measures unless they are of very low cost.

  A reasonable test of the need for a traffic control would be one which determined the historical frequency of occurrence and established the number and rate of accidents within that location under the specific condition and at all other times. At present, information on hazardous locations exists, but on a limited basis and primarily as they relate to roadside hazards.

- Type and number of incidents affected by traffic control

  Traffic control measures cannot be expected to be equally effective in reducing the frequency or severity of incidents. Frequently, the traffic controls implemented during extreme adverse weather conditions are directed at reducing speed through the affected area. While this approach may be effective in reducing accident frequency and the severity of accidents among similar classes of vehicles, it may not be effective in reducing the severity of accidents involving commercial vehicles and passenger vehicles. If the data indicate a significant percentage of auto-truck collisions, consideration should be given to separation of vehicle classes through the affected area either by lane control, route diversion or temporary staging. It is also possible that a review of the data will indicate a problem that might best be resolved through means other than

application of traffic controls. For example, installation of snow fences, specially lighted sections, improved delineators or other permanent installations may present a more cost-effective solution than one which relies on intermittent application of traffic controls. Similarly the type of prevalent accidents (e.g., ran off roadway, sideswipes) can provide information on the type of control or other countermeasure that might be most appropriate.

While these are only examples they do suggest that better use can be made of existing data in the analysis of the hazards created by adverse environmental conditions.

(2) Define How Control Will Reduce Incidents

Once the type and need for traffic control has been tentatively identified based upon the exposure rates the proposed action should be examined in terms of how the control will reduce the frequency or severity of incidents.

The principal objectives of this analysis are to determine what the effect of the control will be on:

. Exposure

. Number or severity of incidents

Each of these tests of a proposed traffic control should yield quantifiable estimates of the effects of implementation.

. Effect on Exposure Rates

The effect of a traffic control on exposure rates can be examined in terms of:

- number and class of vehicles

- type of driver population

The purpose of this analysis is to assure that traffic controls proposed for implementation are consistent with the nature of the hazard generated

by the adverse conditions. For example, if the rate of exposure to the hazard is different for the various vehicle classes, then the control is directed at the class with the highest exposure. An analysis of traffic delays during heavy snowfall conditions may indicate that historically the major cause for delay is attributable to passenger vehicles becoming stranded or otherwise impeding traffic. An appropriate control, in that instance, might be to direct private auto traffic to either secondary roads or predesignated lodging areas.

Similarly, an analysis may indicate a high percentage of delay incidents or accidents related to the onset of adverse weather during peak commuter travel hours. The frequency of these conditions may warrant development of a traffic control program which combines logistical procedures with public broadcast announcements to take advantage of the tendency among commuters to rely on traffic advisories.

Effect Upon Number or Severity of Incidents

Very little can be done within the scope of traffic control efforts to reduce the frequency or severity of adverse weather conditions. Any traffic control that is implemented to counter these effects, however, should have a demonstrable effect on reducing the number or severity of these weather related incidents. Road closure or convoying of traffic may be the only appropriate actions under conditions of severely reduced visibility such as during fog or dust storms, although there continues to be a reliance on controls directed at voluntary speed reduction. In general, voluntary speed reduction contols do not achieve the high level of compliance required to adequately reduce the hazards to travel under conditions of severely limited visibility.

The test of any traffic control implemented to counter the interruption in traffic flow resulting from extreme adverse environmental conditions, of course, should be the extent to which it reduces the delay that would occur if no control were implemented. Imposition of a traffic control will, of itself, create a travel delay in most instances.

This control is warranted if it represents a significant reduction in the delay that would otherwise occur, and can be implemented at a cost which is proportional to the economic costs of delay or loss attributable to accidents.

(3) Determine Payoff from Traffic Control

The reduction in the number or severity of adverse weather incidents effected through traffic control measures should be quantifiable in terms of the dollar benefits. The potential value of these benefits can also serve as an upper limit on the cost that can be incurred within the range of cost effective solutions. Determining the potential benefits of traffic control measures, however, is often complicated by the lack of data on the cost associated with either accidents or delay incidents. Precision in estimating these costs (i.e., the potential benefits) is perhaps less important than consistency in the application of costs to either accident or delay estimates to assure comparability in the analyses of either alternative controls measures or the selection of priority sites for treatment. For that reason it is suggested that national estimates of accident and delay costs will suffice in the development of estimates of the potential benefits to be derived from implementation of a control measure under adverse weather conditions. The benefits of a traffic control should be determined for the same period over which the costs of implementation will be incurred. If, after consideration of each of the various costs associated with implementation of a traffic control measure, the total cost exceeds the benefits by a significant amount on either a percentage or absolute basis, the proposed control should not be considered further.

Occasionally, traffic controls are implemented as the result of political interest in highway programs following the occurrence of spectacular accidents or traffic delays. Although the emotionalism associated with these events is difficult to counter, they generally are rare occurrences and not amenable to cost-effective treatments. An analysis and development of a list of locations at which the installation of traffic controls in adverse weather would yield greater benefits may aid in the selection of controls which are supportable on strong economic grounds rather than on some other less justifiable basis.

5. DETERMINE PROBABILITY OF TRAFFIC CONTROL IMPLEMENTATION

Consideration of a traffic control measure to counter the hazards of extreme adverse environmental conditions should include a realistic assessment of the probability of implementation based upon:

- Implementation costs
- Timing constraints
  - legislation requirements
  - implementation time
- Administrative requirements
  - Federal
  - State
  - Local

(1) Implementation Cost

The cost of implementing a traffic control in adverse weather conditions can be a key factor in the decision to install a traffic control measure and in the design of the control. The estimates of the cost of implementation, therefore, should be as all inclusive and reliable as possible. Costs that should be considered, particularly in the case of controls which rely on a logistical approach, include:

- mobilization costs
- stockpile costs
- overtime costs
- equipment operating costs

Mobilization costs should include those activities associated with both deployment of equipment and personnel, and notification of motorists of the hazardous condition. If the control measure relies on stockpiling of equipment or supplies at strategic locations in anticipation of the adverse weather

conditions, the acquisition cost of these supplies on either a total or prorated basis should be applied to the control cost. Overtime or other extraordinary personnel costs incurred as a result of implementation of the control should also be added to the estimate. Equipment operating costs include those associated with operation and maintenance of permanent signing or other hazard warning devices, as well as those incurred in the temporary use of highway equipment or patrol vehicles.

(2) Timing Constraints

Implementation of specific traffic controls may require modification of existing legislation or statutory authority. In most states the authority to close or otherwise divert traffic on the interstate or primary road sytem rests with the state law enforcement agency, although coordination with the highway agency is required in many instances.

In practice, enforcement agency personnel have considerable authority in the field to initiate the actions necessary to maintain traffic flow or reduce the hazards to travel during adverse conditions. Development or implementation of a traffic control program which will be directed or manned by highway personnel, therefore, will require considerable coordination with enforcement agency personnel, and may require legislative approval if the highway agency is to assume responsibility for the decision to implement a control. In several states, coordination of responsibilities has been achieved through Memoranda of Understanding between police and highway agencies.

The speed with which a traffic control measure can be implemented in response to an adverse weather condition is very often the key to its effectiveness in reducing or eliminating the incidents caused by adverse weather condition. Achieving the necessary degree of responsiveness to impending or existing hazards, generally requires coordination of activities between the enforcement and highway agencies, particularly those of detection and notification of the hazard, and initial implementation of the traffic control. Development of the procedures for assuring the coordination of these activities is often a lengthier and more complex process than design of the on-site control. Because of the importance of these

activities to the success of a traffic control program, however, as much effort as possible should be devoted to codifying these procedures prior to implementation of the traffic control. Often the time required to respond to hazards created by adverse weather conditions can be reduced by establishing one or more alert conditions based upon specified hazard thresholds. For example, several alert conditions leading to full scale implementation of a traffic control measure might be established for specified levels of visibility under fog conditions. The procedures would specify the actions required of each agency under level of control, and designate responsibility for determining and notifying agency personnel of a change in the severity of the hazard.

(3) Administrative Requirements

Implementation of traffic controls during adverse weather conditions very often requires coordinating the use of personnel and movement of traffic on an intejuisdictional basis. For example, diversion of traffic from a limited access highway onto a secondary or other primary road system usually requires assumption of responsibility for traffic control by jurisdictional authorities, either county or city. Often, the cooperation of these jurisdictions is essential in providing adequate traffic management. The content of cooperation and level of assistance may be affected by the generally limited resources available to local jurisdictions. In defining the requirements for implementation of a traffic control to counter the hazards of adverse weather, therefore, it is important to consider the impact of the control on these jurisdictions as a result of either the voluntary or involuntary diversion of traffic into their areas.

Planning of traffic control measures should provide for input from those jurisdictions that might be affected, and should include development of procedures which clearly delineate the responsibilities and authorities of the jurisdictional agencies. These planning activities may also involve owners of lodging or restaurant facilities to provide temporary accommodations in the event that travel is hazardous on all road sytems. Michigan, for example, has developed a road closure plan for severe snow storms that diverts interstate traffic to designated exit facilities.

In defining the requirements for implementation of traffic controls it may be possible also to utilize the approaches or facilities established for operation under the Emergency Highway Traffic Regulation Plan developed by each State.

6. SUMMARY

It should be apparent from the previous discussion that the difficulties encountered by states and local government authorities in dealing with extreme adverse highway environmental conditions can be ascribed to a number of factors. These usually include:

- Limited capability for detecting or predicting isolated adverse conditions
- General lack of objective criteria for determining severity of conditions
- Poorly developed information on systems to alert the highway user
- Poor coordination in mobilizing resources to eliminate or minimize effects of hazardous conditions
- Lack of planning to initiate and maintain traffic control measures promptly.

Although all states, to a greater or lesser degree, experience dangerous environmental conditions on their roadway systems, very few have attempted to establish or maintain a comprehensive approach to limiting the implications of those conditions. One deterrent is, of course, that the costs of developing and implementing solutions based upon technological approaches to many of these problems may be very great.

Logistical solutions which rely on coordination of highway and enforcement agency resources to initiate and manage traffic control measures can achieve levels of effectiveness that are at least comparable, and often better than hardware oriented approaches. Cost is also a consideration in the selection of the logistical approach to implementation of traffic controls, and, therefore, the decision to elect one approach over another should be based upon relative cost-effectiveness.

The remainder of this manual describes the procedures that are applicable in identifying the nature of the need for special traffic controls, and a procedural approach to estimating the relative cost effectiveness of alternative traffic control measures.

The procedures described are neither rigorous nor precise. They do provide a framework for analysis, however, which is consistent with the level of detail of data that is usually available. This framework establishes a logical approach to the identification of the need for, and the level of, investment that is warranted in the implementation of individual traffic control programs.

The last chapter of this handbook describes reporting and evaluation procedures that, if implemented, could aid considerably the development of future traffic control strategies.

III. HAZARD IDENTIFICATION

The hazards of travel during extreme adverse environmental conditions are well known. They are often the cause of multi-car collisions or lengthy travel delays, with resulting human, property, and economic loss totalling in the hundreds of millions of dollars every year. However, while the potential benefits of reducing the hazards created by adverse weather conditions are quite large, the recurring, yet unpredictable, nature of these conditions makes it difficult to develop effective countermeasures. In those instances where traffic controls are relied upon as a countermeasure, the controls that must be applied are typically more labor intensive and costly than routine traffic control programs. The cost of these controls when appropriately applied can be justified by the potential benefits that can accrue from effective hazard reduction, but if the payoffs are high for a successful program, so are the costs for an unsuccessful countermeasure program. The cost incurred in weather-related traffic control measures that result in no significant impact on accident or delay frequency can be counterproductive in terms of the impact on future program justification or budget requests. For that reason, development of a traffic control to counter extreme adverse environmental effects should be preceded by a thorough analysis of the characteristics of the hazard created by these conditions. This analysis should either confirm or deny that:

- The rate of which accidents or delays occur during periods of adverse weather conditions is significantly in excess of the comparable rate for non-adverse conditions

- The economic loss attributable to accidents or delays caused by adverse environmental conditions is equal to or greater than the cost of achieving a significant reduction in the hazard.

In this chapter, we provide a description of the methodologies to be applied in determining the extent of the hazard created by specific adverse environmental conditions. The first portion of the analysis is devoted to determining whether a significant hazard exists as indicated by elevated accident or incident rates during the periods that the conditions exist. The extent of the hazard

can then be expressed in terms of the expected cost of accidents or delays in travel time attributable to their conditions to provide an estimate of the level of investment that is warranted in countering the hazard.

The extent of the hazard created is defined in terms of the expected cost of accidents or delays in travel time attributable to these conditions. The first step in determining the level of severity of the hazard created by environmental conditions is to specify those weather or weather-related conditions which appear to pose the greatest threat to safe highway travel. Once the nature of the hazard is defined, the basic question to be addressed is whether the nature and frequency of occurrence of the condition results in a significantly higher accident rate or number of disruptions in traffic flow than occurs over comparable road classes during those periods when the adverse conditions do not exist. Figure 1 indicates the accident or delay-related data that should be collected for use in making these determinations.

The first step, following compilation of this information, should be to analyze the delay and accident data to determine if the incidents are confined to specific sites or occur in a random fashion throughout the system. This initial analysis is essential to defining the nature of the problem and arriving at an early determination of the type of traffic control that may be required.

This analysis consists of two steps:

- Preliminary analysis of priority locations
- Identification of priority locations.

In the first step, incidence data is plotted and a preliminary determination of priority locations is made. In the second step, each of those locations identified in step 1 is subjected to a statistical test procedure to make a final determination as to whether a problem in fact exists at that location.

1. PRELIMINARY ANALYSIS OF PRIORITY LOCATIONS

The purpose of this phase of the analysis is to develop a preliminary list of hazardous locations which can be subjected to further analysis. Thus, this step provides a "first cut" in the overall hazardous location identification process. There are two activities which comprise the preliminary analysis:

DATA ELEMENT	ACCIDENT REDUCTION CONTROL		DELAY REDUCTION CONTROL	
	ADVERSE CONDITIONS	NON-ADVERSE CONDITIONS	ADVERSE CONDITIONS	NON-ADVERSE CONDITIONS
NUMBER OF ACCIDENTS*	X	X		
NUMBER INVOLVING FATALITIES	X	X		
NUMBER INVOLVING INJURIES	X	X		
NUMBER INVOLVING PROPERTY DAMAGE ONLY	X	X		
FREQUENCY OF CONDITIONS*	X	X	X	X
TRAFFIC VOLUME*	X	X	X	X
NUMBER OF DELAYS*			X	X
LENGTH OF DELAYS*			X	X

**INDICATES MINIMUM DATA REQUIRED FOR ANALYSIS*

Figure 1. Data requirements list.

. Plotting of incidence data

. Preliminary determination of priority locations.

(1) Plotting of Incidence Data

It is recommended that data from the state traffic records system or other sources be plotted on a highway segment map or facsimile as an aid to identifying the pattern of incident occurrences. The data sample should consist of incident data for up to five years under all weather conditions, fair or adverse. The data must contain the location of each incident (accident or delay as specified) and the weather conditions prevalent at the time of the incident. Each individual incident (accident or delay) which occurred during the adverse condition specified is then plotted by location on the scale facsimile or map of the highway segment. (Figure 2 provides an example of a map plot)

(2) Preliminary Determination of Priority Locations

The plot of adverse weather related incidents developed in the preceding activity is now examined visually in order to make a subjective identification of high incidence areas or sites. That is, the plot of accident locations will show higher density of incidents at certain specific sites and/or segments. At site specific locations, this higher density will manifest itself in clusters of incidents in close proximity. For segments, the higher density will manifest itself in the form of a greater overall number of incidents in that segment than appears in other similar segments. A Worksheet (Figure 3) is provided for tabulating this data, and making a preliminary determination of priority locations. Having serially identified all high incidence locations, both site-specific and segment-specific, the engineer can proceed to analyze each of these locations to ascertain the severity of the problem at each location using the simple statistical test procedure described in the following section.

2. IDENTIFICATION OF PRIORITY LOCATIONS

The analysis described in the above section provides a list of specific sites or highway segments which appear to be critical locations during periods of adverse weather conditions. These tentative findings must then be tested

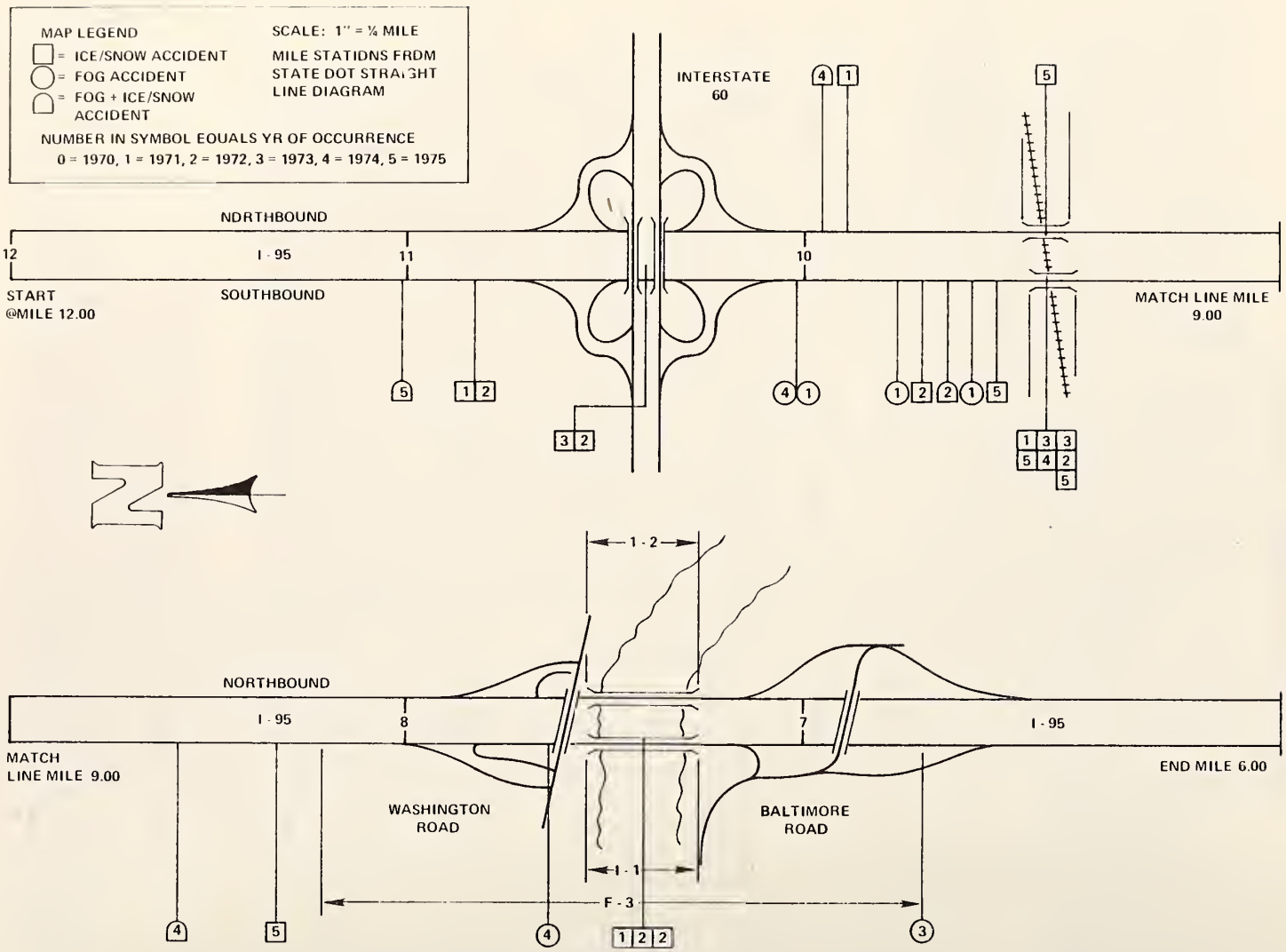

Figure 2. Sample accident location map.

Weather Condition: _____

LOCATIONS	1970	1971	1972	1973	1974	1975	TOTAL
1							
2							
3							
4							
5							
6							
TOTAL							

PERCENTAGE OF INDIVIDUAL TOTAL TO TOTAL NUMBER OF ACCIDENTS $= \frac{T(i)}{T} \times 100$

LIST IN ORDER OF PRIORITY OF TREATMENT REQUIRED BASED UPON ACCIDENT FREQUENCY:

LOCATION	% TOTAL	PRIORITY
_____		
_____		
_____		

Figure 3. Incident frequency by location.

through a statistical comparison of annual incident rates at these locations during periods of inclement and fair weather to determine if a significant difference exists in the incident rates during those conditions. The analysis consists of two components:

- Compilation of incident rates
- Statistical comparison of incident rates.

In the following paragraphs we describe each of these components of the analysis. Following the discussion are worksheets and instructions which provide a step by step guide to the execution of the analysis.

(1) Computation of Incident Rates

For each location identified in the Preliminary Analysis, an average annual incident rate for both fair and adverse weather conditions must be calculated for each year in the sample. These incidents rates for accidents and delays at site-specific locations during fair and inclement conditions are defined in the following paragraphs:

- The location-specific average accident/incident rates for a given year are defined in the following:
  - Location-specific accident* rate for non-adverse conditions
    $$= \frac{\text{No. of accidents in non-adverse conditions}}{\text{MV** passing in non-adverse conditions}}$$
  - Location-specific accident* rate for adverse conditions
    $$= \frac{\text{No. of accidents in adverse conditions}}{\text{MV** passing in adverse conditions}}$$
- Estimates of the number of vehicles passing the site requires estimates of the number of days of adverse and non-adverse conditions for each year in the sample, together with estimates of Average

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* Accidents have been used instead of accidents/incidents for clarity
** MV = Million Vehicles

Daily Traffic (ADT) for the periods of these condition prevailed:

- Total number of vehicles passing site in non-adverse conditions

$$= \frac{\text{Total number of non-adverse days during sample period x ADT for those days}}{10^6}$$

- Total number of vehicles passing site in adverse conditions

$$= \frac{\text{Total number of adverse days during sample year x ADT for those days}}{10^6}$$

Both estimates then are expressed in Million of Vehicles.

. The segment-specific incident rates[1/] are defined as:

- Segment-specific incident rate for non-adverse conditions

$$= \frac{\text{Total no. of incidents in non-adverse conditions}}{\text{MV passing through in non-adverse conditions}}$$

- Segment-specific incident rate for adverse conditions

$$= \frac{\text{Total no. of incidents in adverse conditions}}{\text{MV passing through in adverse conditions}}$$

. The average delay incident rates are defined as:

1/ Highway segments may be defined as a section between exits which will avoid the necessity for stating segment rates in terms of million vehicle miles.

- Average delay rate for non-adverse conditions

  $$= \frac{\text{No. of delays occurring in non-adverse conditions}}{\text{No. of non-adverse days}}$$

- Average delay rate for adverse conditions

  $$= \frac{\text{No. of delays occurring in adverse conditions}}{\text{No. of adverse days}}$$

Four of the eight definitions presented above require estimates of the total number of adverse and non-adverse days during the sample period, and six of those definitions require estimates of ADT for those types of days. If estimates of ADT for these conditions are not available, it will be necessary to develop an estimate of traffic volume during the periods of adverse weather conditions.

Figure 4 following this page presents a worksheet for calculation of the above rates. The procedures for completing the worksheet are described below.

- Column Headings: Enter the dates for the years/periods for which data is available.

- Line 1: Enter the total number of incidents in the sample period during adverse conditions. This number should be available from the accident records data base, or in the case of delays from enforcement agency or maintenance reports.

- Line 2: Enter the number of incidents occurring during non-adverse conditions from data sources comparable to those used in preparing the estimate in line 1.

- Line 3: Enter the average number of days in which weather conditions of interest prevailed. This value can be estimated from historical data maintained by weather services. The number of days in which accidents occurred during adverse conditions may also be used, but will tend to inflate the accident rate.

- Line 4: Enter number of days in a year in which specific adverse weather conditions did not occur.

LOCATION:

WEATHER CONDITION:

TYPE OF INCIDENT ☐ ACCIDENT ☐ DELAY

INCIDENT RATE CALCULATION	YEAR 1 __TO__	YEAR 2 __TO__	YEAR 3 __TO__	YEAR 4 __TO__	YEAR 5 __TO__
1. Total number of incidents in the period during adverse conditions.					
2. Total number of incidents in the period during non-adverse conditions.					
3. Average number of days conditions prevailed.					
4. Average number of non-adverse days.					
5. Average daily traffic volume for adverse days.					
6. Average daily traffic volume for non-adverse days.					
7. Total traffic volume during the period in adverse conditions. [(Line 5 x Line 3) /10^6]					
8. Average traffic volume during the same period in non-adverse conditions. [(Line 6 X Line 4)/ 10^6]					
9. Incident rate in adverse conditions. [Line 1 ÷ Line 7]					
10. Incident rate in non-adverse conditions. [Line 2 ÷ Line 8]					

ENTER THE INCIDENT RATES IN THE FOLLOWING TABLE.

YEAR/PERIOD			INCIDENT RATE DURING ADVERSE CONDITIONS (LINE 9)	INCIDENT RATE DURING NON-ADVERSE CONDITIONS (LINE 10)
YEAR	FROM: (Mo.)	TO: (Mo.)		
____	____	____		
____	____	____		
____	____	____		
____	____	____		
____	____	____		
AVERAGE				

Figure 4. Hazardous location identification worksheet.

- Line 5: If traffic volume data is not maintained or readily available for periods of adverse and non-adverse conditions, a reasonable approximation should be made of the reduced volume during adverse conditions.

- Line 6: Enter the Annual Average Daily Traffic volume estimates for the location/segment from traffic count or other volume estimates.

- Line 7: Develop an estimate of the total traffic volume during adverse conditions.

- Line 8: Develop a comparable estimate for non-adverse conditions.

- Line 9: Estimate the incident rate for adverse conditions as shown on the worksheet.

- Line 10: Estimate the incident rate for non-adverse conditions as shown on the worksheet.

The Worksheet is completed by transferring the rates calculated on Lines 9 and 10 to the table at the bottom of the sheet and averaging the rates for the periods analyzed.

(2) Statistical Comparison of Adverse and Non-Adverse Incident Rates

The results of the previous analysis are the average incident rates for adverse and non-adverse conditions at a specific location. Although it is quite likely that the rates are different under these two sets of conditions, the difference must be tested statistically to determine if it is significant, or just due to the typical variance in analytical results of this nature.

A Worksheet (Figure 5) has been provided as an aid in analyzing the significance of the observed variance in rates. Other than the following comments, the procedures for completing the worksheet are not described in this text, as they are contained in the worksheet.

TYPE OF INCIDENT: ☐ ACCIDENT
☐ DELAY

REQUIRED DATA/COMPUTATION	ROW No.	LOCATION 1	LOCATION 2	LOCATION 3	LOCATION 4	LOCATION 5	LOCATION 6
*INCIDENT RATES BY PERIOD		— —	— —	— —	— —	— —	— —
– PERIOD 1: _____							
**DURING NON-ADVERSE CONDITIONS	1						
**DURING ADVERSE CONDITIONS	2						
– PERIOD 2: _____		— —	— —	— —	— —	— —	— —
**DURING NON-ADVERSE CONDITIONS	3						
**DURING ADVERSE CONDITIONS	4						
– PERIOD 3: _____		— —	— —	— —	— —	— —	— —
**DURING NON-ADVERSE CONDITIONS	5						
**DURING ADVERSE CONDITIONS	6						
– PERIOD 4: _____		— —	— —	— —	— —	— —	— —
**DURING NON-ADVERSE CONDITIONS	7						
**DURING ADVERSE CONDITIONS	8						
– PERIOD 5: _____		— —	— —	— —	— —	— —	— —
**DURING NON-ADVERSE CONDITIONS	9						
**DURING ADVERSE CONDITIONS	10						
*TOTAL: T = SUM ROWS 1-10	11						
*P = NO. PERIODS IN SAMPLE	12						
*COMPUTE: $M = T^2 \div (2 \times P)$	13						
*COMPUTE: A = SUM ROWS 1, 3, 5, 7, and 9	14						
*COMPUTE: B = SUM ROWS 2, 4, 6, 8, and 10	15						
*COMPUTE: C = SUM ROWS OF ROWS 1-10	16						
*COMPUTE: $D = (A^2 + B^2) \div P$	17						
*COMPUTE: X = C – M	18						
*COMPUTE: Y = D – M	19						
*COMPUTE: Z = X – Y	20						
*COMPUTE: $\mu = Z \div (2xP-2)$	21						
*COMPUTE: $Y \div \mu$	22						

Figure 5. Incident analysis worksheet.

The results of the foregoing analyses are a set of locations and average annual incident rates at these locations during fair and inclement weather conditions for a period of about 5 years. This information can be put in tabular form, as shown in the worksheet in Figure 5.

The first ten row entries are a listing of the incidence rates for each location computed in the analysis above. The entries for each of the remaining rows, rows 11-22, can be completed after the values for rows 1-10 have been entered. Rows 11-21 are intermediate steps used to obtain the statistical parameter appearing in row 22. The value of the entry in row 22 is used to determine whether a statistically significant difference exists in the adverse and non-adverse condition incident rates at a given location. This determination is made as follows. For each location compare the value appearing in row 22 with the value corresponding to the number of years in the sample in the table of critical values appearing in Table 1 of this chapter.

- If the value in row 22 is larger than the critical value corresponding to the number of years in the sample, there is a hazard created by adverse weather conditions.

- If the value in row 22 is smaller than the critical value, no hazard is created by adverse weather conditions.

A list of locations where traffic control might be warranted can be developed by testing each location from the preliminary list using the process outlined above.

3. ESTIMATING COSTS ASSOCIATED WITH HAZARDOUS CONDITIONS

Having identified all locations at which a hazard is created by adverse weather conditions, these locations can be further prioritized by the potential benefit that would accrue from implementation of a traffic control. Separate approaches are required for estimating the benefits associated with accident reduction and delay reduction controls. These estimates can be prepared at one of two levels of detail, depending upon the availability of data.

NUMBER OF YEARS IN SAMPLE	CRITICAL VALUE
1	*
2	8.53
3	4.54
4	3.78
5	3.46
6	3.28
7	3.18
8	3.10
9	3.05
10	3.01

*TEST NOT POSSIBLE

Table 1. Critical values for significance

(1) Accident Costs

The cost of accidents attributable to adverse environmental conditions is a function of both the frequency and severity of the accidents. For those locations for which the severity of the accident is known, in terms of fatalities, injuries, and property damage, a reasonable estimate can be developed for the cost of accidents at these locations. The damage estimates provided by enforcement personnel at the site vary considerably in accuracy, and do not include any settlements under damage suits arising from the accident. For that reason it is recommended that the national estimates of the costs to society of fatal and non-fatal accidents[2/] be used in estimating the costs of accidents associated with adverse conditions. Use of these estimates assures consistency in the application of cost and avoids an overstatement of priorities that may not be warranted.

The estimated costs of accidents at various highway locations represent the potential benefit to society of implementing a traffic control or other improvement at that location. If the control is totally effective, the benefit of implementation would, of course, equal the historical or projected accident costs.

The basic procedure for estimating these costs is described below:

- If information is available for each location on the type and severity of accidents, these numbers should be averaged over the number of years the data is available to obtain an annual average accident frequency for fatal, injury, and property damage only (PDO) accidents. These averages should then be applied to the estimates of accident costs for these categories and summed to obtain an annual accident cost at that location.

- If the accident records do not support a separate treatment of accidents by type, it will be necessary to use a composite estimate of accident costs to obtain an order of magnitude of the potential benefits of improvements at each location.

2/ National Highway Traffic Safety Administration, 1975 Societal Costs of Motor Vehicle Accidents

This cost data for each location should be tabulated with the data on accidents rates and frequency, and reviewed to determine the priorities that should be assigned on the basis of accident costs.

(2) Travel Delay Costs

Determination of the costs to the highway user and society as a result of travel delays is difficult. The process suffers generally from both a lack of data on the frequency and duration of traffic delay incidents, and lack of consensus on the appropriate cost per hour to assign to delays incurred in travel time. The cost associated with late arrival of passenger and commercial vehicles must consider such factors as the possible effects on motorist wages, and the more complex set of costs to society of late delivery of economic goods.

The scope of these guidelines does not include an analysis of the cost incurred by a motorist as a result of delay. A recent study[3/] established a delay cost per hour of $6.00 per vehicle unit. This figure provides a reasonable guideline for use in the absence of any other defensible value.

In estimating the potential benefits of a traffic control to reduce delay times, these guidelines suggest that the benefit should be evaluated in terms of the effect of the control in reducing the delay time. Alternative controls are compared on the basis of the incremental cost of achieving the next level of effectiveness.

This approach does not permit the traditional cost-benefit analysis of a traffic control. If this is desirable, it will be necessary to estimate the total number of hours of delay incurred by highway users as a result of delay incidents at specific highway locations. This estimate should be based on historical information on delay frequencies and durations which has been averaged to established an annual estimate of total delay hours.

3/ Utah Department of Transportation, Economic Impacts of Snow-Induced Traffic Delays and Safety

* * *

This chapter described the procedures for analyzing the effects of adverse environmental conditions on the frequency of accidents and traffic delays. This analysis is essential in determining the extent of the need to counter the hazards created by these conditions, and in defining the nature of the problem to be addressed by any proposed countermeasure. As an aid to using the procedures and worksheets suggested in the chapter, a series of example worksheets have been prepared based upon data taken from several sources. These sample worksheets are described in Figures 6 through Figure 10.

Weather Condition: FOG

LOCATIONS	1970	1971	1972	1973	1974	1975	TOTAL
1					6	1	7
2					2	2	4
3					5	6	11
4					2	6	8
5					4	2	6
6					3	3	6
TOTAL					22	20	42

PERCENTAGE OF INDIVIDUAL TOTAL TO TOTAL NUMBER OF ACCIDENTS $= \frac{T(i)}{T} \times 100$

LIST IN ORDER OF PRIORITY OF TREATMENT REQUIRED BASED UPON ACCIDENT FREQUENCY:

LOCATION	% TOTAL	PRIORITY
3	26 %	1
4	18 %	2
1	17 %	3

Figure 6. Incident frequency by location. (Example)

LOCATION: 4-MILE 75. I-80

WEATHER CONDITION: FOG

TYPE OF INCIDENT: ☒ ACCIDENT ☐ DELAY

INCIDENT RATE CALCULATION	YEAR 1 — TO —	YEAR 2 — TO —	YEAR 3 — TO —	YEAR 4 74 TO 75	YEAR 5 75 TO 76
1. Total number of incidents in the period during adverse conditions.				2	6
2. Total number of incidents in the period during non-adverse conditions.				28	24
3. Average number of days conditions prevailed.				30	45
4. Average number of non-adverse days.				335	320
5. Average daily traffic volume for adverse days.				12,000	12,500
6. Average daily traffic volume for non-adverse days.				16,000	16,500
7. Average traffic volume during the period in adverse conditions. [(Line 5 X Line 3)/ 10^6]				.360	.563
8. Average traffic volume during the same period in non-adverse conditions. [(Line 6 X Line 4)/ 10^6]				5.36	5.28
9. Incident rate in adverse conditions. [Line 1 ÷ Line 7]				5.56	10.66
10. Incident rate in non-adverse conditions. [Line 2 ÷ Line 8]				5.22	4.55

ENTER THE INCIDENT RATES IN THE FOLLOWING TABLE.

YEAR/PERIOD			INCIDENT RATE DURING ADVERSE CONDITIONS (LINE 9)	INCIDENT RATE DURING NON-ADVERSE CONDITIONS (LINE 10)
YEAR	FROM: (Mo.)	TO: (Mo.)		
74	1/1	12/31	5	5
75	1/1	12/31	11	5
AVERAGE			8	5

Figure 7. Hazardous location identification worksheet. (Example)

LOCATION 1-MILE 10.5 I-80

WEATHER CONDITION FOG

TYPE OF INCIDENT ☒ ACCIDENT ☐ DELAY

INCIDENT RATE CALCULATION	YEAR 1 —TO—	YEAR 2 —TO—	YEAR 3 —TO—	YEAR 4 74 TO 75	YEAR 5 75 TO 76
1. Total number of incidents in the period during adverse conditions.				6	1
2. Total number of incidents in the period during non-adverse conditions.				50	50
3. Average number of days conditions prevailed.				45	30
4. Average number of non-adverse days.				320	335
5. Average daily traffic volume for adverse days.				11,000	10,000
6. Average daily traffic volume for non-adverse days.				15,000	14,500
7. Average traffic volume during the period in adverse conditions. [(Line 5 X Line 3)/ 10^6]				495	.435
8. Average traffic volume during the same period in non-adverse conditions. [(Line 6 X Line 4)/ 10^6]				4.80	4.86
9. Incident rate in adverse conditions. [Line 1 ÷ Line 7]				12.12	2.30
10. Incident rate in non-adverse conditions. [Line 2 ÷ Line 8]				10.42	10.30

ENTER THE INCIDENT RATES IN THE FOLLOWING TABLE.

YEAR/PERIOD			INCIDENT RATE DURING ADVERSE CONDITIONS (LINE 9)	INCIDENT RATE DURING NON-ADVERSE CONDITIONS (LINE 10)
YEAR	FROM: (Mo.)	TO: (Mo.)		
____	____	____		
____	____	____		
____	____	____		
74	1/1	12/31	12	10
75	1/1	12/31	2	10
AVERAGE			7	10

Figure 8. Hazardous location identification worksheet. (Example)

LOCATION 3 - BRIDGE AT MILE 105.1 I-80

WEATHER CONDITION FOG

TYPE OF INCIDENT ☒ ACCIDENT ☐ DELAY

INCIDENT RATE CALCULATION	YEAR 1 — TO —	YEAR 2 — TO —	YEAR 3 — TO —	YEAR 4 74 TO 75	YEAR 5 75 TO 76
1. Total number of incidents in the period during adverse conditions.				5	6
2. Total number of incidents in the period during non-adverse conditions.				60	55
3. Average number of days conditions prevailed.				35	35
4. Average number of non-adverse days.				330	330
5. Average daily traffic volume for adverse days.				11,500	11,500
6. Average daily traffic volume for non-adverse days.				16,500	17,000
7. Average traffic volume during the period in adverse conditions. [(Line 5 X Line 3)/ 10^6]				.4025	.4025
8. Average traffic volume during the same period in non-adverse conditions. [(Line 6 X Line 4)/ 10^6]				5.445	5.610
9. Incident rate in adverse conditions. [Line 1 ÷ Line 7]				12.42	14.91
10. Incident rate in non-adverse conditions. [Line 2 ÷ Line 8]				11.02	9.80

ENTER THE INCIDENT RATES IN THE FOLLOWING TABLE.

YEAR/PERIOD			INCIDENT RATE DURING ADVERSE CONDITIONS (LINE 9)	INCIDENT RATE DURING NON-ADVERSE CONDITIONS (LINE 10)
YEAR	FROM: (Mo.)	TO: (Mo.)		
74	1/1	12/31	12	11
75	1/1	12/31	15	10
AVERAGE			27	21

Figure 9. Hazardous location identification worksheet. (Example)

TYPE OF INCIDENT: ☐ ACCIDENT
☐ DELAY

REQUIRED DATA/COMPUTATION	ROW No.	LOCATION 1	LOCATION 2	LOCATION 3	LOCATION 4	LOCATION 5	LOCATION 6
*INCIDENT RATES BYPERIOD		— —	— —	— —	— —	— —	— —
– PERIOD 1: _____							
**DURING NON-ADVERSE CONDITIONS	1	11		11	5		
**DURING ADVERSE CONDITIONS	2	12		12	5		
– PERIOD 2: _____		— —	— —	— —	— —	— —	— —
**DURING NON-ADVERSE CONDITIONS	3	10		10	5		
**DURING ADVERSE CONDITIONS	4	2		15	11		
– PERIOD 3: _____		— —	— —	— —	— —	— —	— —
**DURING NON-ADVERSE CONDITIONS	5						
**DURING ADVERSE CONDITIONS	6						
– PERIOD 4: _____		— —	— —	— —	— —	— —	— —
**DURING NON-ADVERSE CONDITIONS	7						
**DURING ADVERSE CONDITIONS	8						
– PERIOD 5: _____		— —	— —	— —	— —	— —	— —
**DURING NON-ADVERSE CONDITIONS	9						
**DURING ADVERSE CONDITIONS	10						
*TOTAL: T = SUM ROWS 1-10	11	35		48	26		
*P = NO. PERIODS IN SAMPLE	12						
*COMPUTE: $M = T^2 \div (2 \times P)$	13	308.7		579.61	168.7		
*COMPUTE: A = SUM ROWS 1, 3, 5, 7, and 9	14	20.72		20.82	9.77		
*COMPUTE: B = SUM ROWS 2, 4, 6, 8, and 10	15	14.42		27.33	16.22		
*COMPUTE: C = SUM ROWS OF ROWS 1-10	16	366.85		594.04	192.5		
*COMPUTE: $D = (A^2 + B^2) \div P$	17	318.63		590.20	179.27		
*COMPUTE: X = C – M	18	58.15		14.44	23.63		
*COMPUTE: Y = D – M	19	9.92		10.60	10.4		
*COMPUTE: Z = X – Y	20	48.22		3.84	13.23		
*COMPUTE: $\mu = Z \div (2xP-2)$	21	24.11		1.92	6.61		
*COMPUTE: $Y \div \mu$	22	.41		5.51	1.57		

Figure 10. Incident analysis worksheet. (Example)

IV. TRAFFIC CONTROL MEASURE SELECTION

This chapter describes the methodologies for selection of special traffic controls to reduce the frequency or severity of accidents or traffic delays on limited access highways caused by adverse environmental conditions. The overall approach to traffic control selection presented in this chapter is based upon cost-effectiveness analysis. Currently, however, the limited availability and reliability of data on the effectiveness of traffic control measures does not permit a traditional approach to evaluating the cost-effectiveness of alternative control measures. Thus, the approach taken in these guidelines is to describe the procedures for determining the level of effectiveness that should be attained by a traffic control in order to be cost-effective. It is then left to the traffic engineer's judgement to decide whether the proposed control can achieve the level of effectiveness required.

Thus, the emphasis in these guidelines is on assessing the need for and determining the level of investment that is warranted in traffic controls to counter the effects of extreme adverse weather conditions. The purpose of the analysis described in these guidelines is to minimize the reliance on subjective judgement in the decision to implement a program to counter adverse environmental conditions. The results of the analysis are also helpful in establishing the cost of implementing a traffic control that is reasonable in terms of the expected benefits of the control.

It is recognized that a large portion of the effort in both designing and implementing control measures that will effectively counter the hazards of extreme weather conditions, is in obtaining the cooperation and coordinating the activities of the organizations and personnel that will be involved in control implementation. The diversity of adverse weather conditions that can affect highway travel and the variety of controls that may be implemented to counter these hazards make it difficult to provide a generalized set of implementation procedures that would be useful over a wide range of applications. The usefulness of generalized procedures is hampered still further by the differences among the states in terms of the assignment of legal authority and responsibility for traffic control on limited access highways. Therefore, while the guidelines

provided in this manual do not describe a model set of procedures for implementing various control measures, Appendix A to the manual does include brief descriptions of controls that have been applied to counter the hazards created by adverse weather conditions. The techniques described in Appendix A are provided only as examples of special traffic controls that have been implemented, they are not presented as proven cost-effective techniques that are applicable universally. The decision to implement a traffic control to counter the hazards created by adverse weather should be based upon an analysis of the merits of a candidate control given the conditions at a specific location.

Some of the major considerations that should be taken into account in the design or selection of a control during adverse weather conditions are summarized below as a basic checklist of criteria that should be applied in the process.

1. IDENTIFICATION OF ALTERNATIVE CONTROL MEASURES

Special traffic controls that are candidates for implementation to reduce the hazards to highway travel created by adverse environmental conditions should be reviewed in terms of:

- Applicability to site-specific or general condition
- Appropriateness of traffic control in reducing hazard
- Potential of control for achieving desired motorist response.

Each of these considerations is described separately below.

(1) Applicability of Site-Specific vs. General Traffic Controls

Traffic controls which are applicable to generally hazardous conditions (e.g., snow storms) and rely on logistical approaches (e.g., convoying of motorists) can also be applicable to situations in which a similar hazard is confined to a limited area. Because the control measures do not rely on a voluntary action by the highway user, they are very effective in reducing the level of hazard presented by the environmental conditions. Traffic controls based upon a procedural

or logistical approach, however, can be costly to implement and may not permit the quick response to hazardous conditions required in many instances.

Where the hazard is confined to specific locations, particularly remote locations, a traffic control device may provide the most cost-effective approach. The high level of effectiveness apparently achieved with some traffic control devices, at specific locations, however, has tended to result in an undue generalized reliance at other sites on a particular method of traffic control to achieve a desired motorist response. To be effective, a traffic control device should provide a warning and indicate the appropriate hazard evasion action and should be located in close proximity to a potential hazard that can be perceived as real by the approaching motorist. If a traffic control device which warns of a hazard is remote from the affected area, it may temporarily increase the level of attention of the motorist to roadway conditions, but is of limited effectiveness in achieving the desired response unless supplemented by additional positive controls.

(2) Appropriateness of Control in Reducing Hazard

In considering various traffic controls for potential implementation, the traffic engineers should assure that the action imposed by the traffic control is the most appropriate one, within reasonable limits of budget and authority, to reduce the hazard to highway users. The circumstances surrounding accidents or delay incidents should be examined as thoroughly as possible to determine the motorist action which, if taken, would have avoided or reduced the severity of the incident. For example, many traffic controls are directed at reducing the speed of vehicles through affected sections. While this action may accomplish a reduction in the frequency and severity of accidents, a complementary action such as confining trucks to a common lane may eliminate automobile-truck collisions and further reduce accident severity.

The assessment of the appropriateness of a traffic control should also consider alternatives to traffic control that may be of comparable cost-effectiveness. Alternatives might include hazard abatement activities, and development of programs to educate highway users in the appropriate action to take when encountering specific environmental conditions.

(3) Potential of Control for Achieving Desired Motorist Response

Traffic controls vary considerably in their ability to achieve the response from motorists intended by the control. As has been discussed in previous chapters, motorist reaction to controls is a function of a number of characteristics of the control, the most important of which include:

- location
- method of communicating desired motorist response
- credibility.

The probable effect of each of these aspects of a proposed traffic control should be assessed as part of the selection process. For example, is the control installed in the area of the hazard, and does it make clear to the motorist what is the appropriate hazard avoidance action? Just as importantly, have adequate procedures been established to assure that the control is removed as soon as possible after the hazard has passed? In most instances, if more than one of these characteristics of a traffic control under consideration is rated as negative or neutral in its effect on motorist behavior, the control should not be considered further in that application.

Typically, it is not difficult for the traffic engineer to develop a list of candidate traffic controls or locations at which controls might be implemented to reduce the occurrence of accidents or traffic delays under adverse conditions. The difficulty generally arises in the selection of the most appropriate control from among the alternatives, and in justifying the cost of implementing the selected traffic control. Methodologies exist for making the selection and developing the justification. The disadvantage of these methodologies to the traffic engineer is that they rely heavily on the establishment of a level of effectiveness for each alternative measure and the calculation of the cost-effectiveness or cost-benefits to be achieved by the traffic control.

The assessment methodology presented in these guidelines takes a somewhat unorthodox approach in the treatment of the effectiveness of various traffic control measures. This approach is necessitated by:

- A general lack of reliable data on the effectiveness of proposed control measures

- The difficulty of extending the experience with a successful control measure to another location which may differ in several important characteristics from the pilot site.

The methodology presented in this manual enables the engineer to compute the level of effectiveness that the traffic control must achieve in order to be cost-effective. More specifically, the methodology generates an estimate of the percentage reduction in accidents or delay occurrences which must be attained with the traffic control measure in order to achieve that condition where the costs of the measure and the benefits derived from it are equal. The approach provides the engineer with a method for quantitatively differentiating among control measures without putting undue reliance on a prior estimate of effectiveness, as in the case with the traditional cost-effectiveness approach. In presenting these methodologies, the procedures for developing traffic control costs are discussed first, followed by those for evaluating and selecting the appropriate control.

2. DETERMINATION OF TRAFFIC CONTROL IMPLEMENTATION COSTS

The computation of the costs of implementing a traffic control follows a straightforward procedure. It is important that the procedures described are followed, however, to assure comparability among the cost estimates developed for alternative controls.

(1) General Approach

The descriptive data elements required to conduct the analysis include:

- Location of delay

- Average daily traffic (ADT) volume

- Number of lanes in the direction of flow

- Traffic density (by vehicle class).

For a given control technique, the following cost categories are needed to estimate the total cost of control:

- Initial Cost
- Set-up Cost
- Annual Operating Cost
- Maintenance Cost.

The costs incurred in each category vary throughout the service life of a traffic control measure, and should be converted into a uniform annual cost to permit comparison among controls. Intermittent controls, such as convoying, should be costed on the basis of one application and then multiplied by the average number of times a control will be implemented in a year. The data requirements for calculating the Equivalent Uniform Annual Cost of control are:

- Initial Cost
- Annual Cost
- Terminal Value
- Service Life
- Interest Rate.

The first two cost categories are best obtained from historical initial and annual operating costs. If historical information is not available, the data used to develop these estimates should be at as low a level of detail as possible. For procedural controls, the estimate of the cost of a one-time implementation should be multiplied by the number of times the control is expected to be implemented in a year to obtain an approximate annual cost. If the annual costs are assumed to vary over the service life of the system due to technological changes and highway operational improvements, these cost estimates are converted to the equivalent annual or present worth of costs of control using the procedures described in this section.

The terminal value of a traffic control device is the difference between the monetary value at the end of the period and the future costs associated with removal, repair, transfer, and/or sale. For example, signs that are usable at more than one location, will have a significant terminal value and hence this value

should be included in the analysis. Most controls, however, will have a low terminal value.

The interest rate chosen for calculating control cost should be based on the rate for applied in other investment opportunities, or the prevailing borrowing rate. The formulas presented in this section may also be used with a zero interest rate.

The procedure for computing the Equivalent Uniform Annual Cost of control using the available cost estimates are described in the following section.

(2) Procedural Approach

The steps involved in computing the cost of a traffic control are outlined in the Cost Estimating Worksheet (Figure 11). As an aid to completing that worksheet, a sample table has been included in the end of this this chapter for use in the calculation of interest amounts and present values.

The procedures for completing the Cost Estimating Worksheet are described below:

Line 1: For each candidate control measure, enter the initial cost of implementation on line 1. These cost estimates are derived using purchase costs and installation costs derived from cost data on comparable installations, detailed estimates, or bid prices.

Line 2: Enter service life of the equipment associated with the traffic control measure under consideration. Convert this value to common periods in months or years to get a consistent set of data, for comparison purposes. For example, if the service life of one equipment set is 5 months and that of other is 2 years then consider the number of periods as 5 and 2 x 12, or 24, respectively. This conversion is necessary for computing the cost using the tables provided in the manual.

Line 3: Estimate the annual operating costs. These costs are assumed generally to be constant. However, annual costs may vary over the service time of equipment. A reliable average annual cost should be used when this situation is encountered. When the traffic control includes the assignment of personnel at a site, the operating cost includes labor cost,

TRAFFIC CONTROL _____

1.	INITIAL COST	$_____
2.	SERVICE LIFE OF EQUIPMENT	_____
3.	ANNUAL OPERATING	_____
4.	MAINTENANCE COSTS	_____
5.	TERMINAL VALUE	_____
6.	INTEREST RATE _____%	
7.	CAPITAL RECOVERY FACTOR (FROM FIGURE 12 OR EQUIVALENT)	_____
8.	SINKING FUND FACTOR (FROM FIGURE 12 OR EQUIVALENT)	_____
9.	EQUIVALENT UNIFROM ANNUAL COST (LINE 1 x LINE 7 + LINE 3 + LINE 4 – LINE 5 x LINE 8)	$_____

Figure 11. Cost estimating worksheet.

transportation cost, and the purchase and operating cost of equipment used on a temporary basis at that site. To arrive at an annual cost, these costs should be multiplied by the estimated number of times a control will be implemented at a site.

Line 4: Estimate the annual cost for maintaining the traffic control device or system.

Line 5: Enter the estimated terminal value of equipment, if any.

Line 6: Enter the applicable interest rate for the cost of capital. A decision must be made as to whether or not interest rates will be included in the calculation of cost. A zero interest rate may be used if the cost of capital is not regarded as significant.

Line 7: Compute the Capital Recovery Factor using the formula presented in Figure 12, for a traffic control whose lifetime is n periods (from Line 2) and where the interest rate is i% (from Line 6; e.g., 10% in Figure 12).

Line 8: Enter the Sinking Fund Factor (SFF) for a control whose service time is n periods (from Line 2), where the interest rate is i% (from Line 6).

Line 9: Obtain the Equivalent Uniform Annual Cost (EUAC) using the formula presented in the worksheet.

Once the cost of each proposed traffic control has been determined, it can be evaluated in terms of its effectiveness in achieving a reduction in delay times or accident rates. The procedures for making these assessments are presented separately in the following sections.

3. DETERMINATION OF DELAY REDUCTION CONTROL EFFECTIVENESS

This section describes a methodology for determining the effectiveness of alternative traffic control measures that are directed primarily at reducing traffic delays created by adverse environmental conditions. The comparison of effectiveness of each alternative is an important step in the selection of the appropriate measure. The basic approach to evaluating and selecting an appropriate traffic control is to examine the relative costs of implementing alternative control measures, and the potential reduction in delay time associated with each measure to arrive at a level of cost-effectiveness.

i = 10% COMPOUND INTEREST FACTORS

n	Single Payment		Uniform Series				n
	Compound Amount Factor caf'	Present Worth Factor pwf'	Sinking Fund Factor sff	Capital Recovery Factor crf	Compound Amount Factor caf	Present Worth Factor pwf	
	Given P To find S $(1+i)^n$	Given S To find P $\frac{1}{(1+i)^n}$	Given S To find R $\frac{i}{(1+i)^n-1}$	Given P To find R $\frac{i(1+i)^n}{(1+i)^n-1}$	Given R To find S $\frac{(1+i)^n-1}{i}$	Given R To find P $\frac{(1+i)^n-1}{i(1+i)^n}$	
1	1.100	0.9091	1.00000	1.10000	1.000	0.909	1
2	1.210	0.8264	0.47619	0.57619	2.100	1.736	2
3	1.331	0.7513	0.30211	0.40211	3.310	2.487	3
4	1.464	0.6830	0.21547	0.31547	4.641	3.170	4
5	1.611	0.6209	0.16380	0.26380	6.105	3.791	5
6	1.772	0.5645	0.12961	0.22961	7.716	4.355	6
7	1.949	0.5132	0.10541	0.20541	9.487	4.868	7
8	2.144	0.4665	0.08744	0.18744	11.436	5.335	8
9	2.358	0.4241	0.07364	0.17364	13.579	5.759	9
10	2.594	0.3855	0.06275	0.16275	15.937	6.144	10
11	2.853	0.3505	0.05396	0.15396	18.531	6.495	11
12	3.138	0.3186	0.04676	0.14676	21.384	6.814	12
13	3.452	0.2897	0.04078	0.14078	24.523	7.103	13
14	3.797	0.2633	0.03575	0.13575	27.975	7.367	14
15	4.177	0.2394	0.03147	0.13147	31.772	7.606	15
16	4.595	0.2176	0.02782	0.12782	35.950	7.824	16
17	5.054	0.1978	0.02466	0.12466	40.545	8.022	17
18	5.560	0.1799	0.02193	0.12193	45.599	8.201	18
19	6.116	0.1635	0.01955	0.11955	51.159	8.365	19
20	6.727	0.1486	0.01746	0.11746	57.275	8.514	20
21	7.400	0.1351	0.01562	0.11562	64.002	8.649	21
22	8.140	0.1228	0.01401	0.11401	71.403	8.772	22
23	8.954	0.1117	0.01257	0.11257	79.543	8.883	23
24	9.850	0.1015	0.01130	0.11130	88.497	8.985	24
25	10.835	0.0923	0.01017	0.11017	98.347	9.077	25
26	11.918	0.0839	0.00916	0.10916	109.182	9.161	26
27	13.110	0.0763	0.00826	0.10826	121.100	9.237	27
28	14.421	0.0693	0.00745	0.10745	134.210	9.307	28
29	15.863	0.0630	0.00673	0.10673	148.631	9.370	29
30	17.449	0.0573	0.00608	0.10608	164.494	9.427	30
31	19.194	0.0521	0.00550	0.10550	181.943	9.479	31
32	21.114	0.0474	0.00497	0.10497	201.138	9.526	32
33	23.225	0.0431	0.00450	0.10450	222.252	9.569	33
34	25.548	0.0391	0.00407	0.10407	245.477	9.609	34
35	28.102	0.0356	0.00369	0.10369	271.024	9.644	35
40	45.259	0.0221	0.00226	0.10226	442.593	9.779	40
45	72.890	0.0137	0.00139	0.10139	718.905	9.863	45
50	117.391	0.0085	0.00086	0.10086	1163.909	9.915	50
55	189.059	0.0053	0.00053	0.10053	1880.591	9.947	55
60	304.482	0.0033	0.00033	0.10033	3034.816	9.967	60
65	490.371	0.0020	0.00020	0.10020	4893.707	9.980	65
70	789.747	0.0013	0.00013	0.10013	7887.470	9.987	70
75	1271.895	0.0008	0.00008	0.10008	12708.954	9.992	75
80	2048.400	0.0005	0.00005	0.10005	20474.002	9.995	80
85	3298.969	0.0003	0.00003	0.10003	32979.690	9.997	85
90	5313.023	0.0002	0.00002	0.10002	53120.226	9.998	90
95	8556.676	0.0001	0.00001	0.10001	85556.760	9.999	95
100	13780.612	0.0001	0.00001	0.10001	137796.123	9.999	100

WHEN i = 0,

CAPITAL RECOVERY FACTOR = 1/n
SINKING FUND FACTOR = 1/n
PRESENT WORTH FACTOR = 1

Figure 12. Sample interest table.

While, as a secondary benefit, application of an appropriate delay reduction control may also reduce the number or severity of accidents arising from interruption of traffic flow on a limited access highway, this methodology addresses only those controls for which the primary purpose is maintenance of traffic at minimum delay under adverse conditions. These conditions may include, for example:

- Mudslides
- Flooding
- Snow or Ice.

The delay time incurred by highway users upstream of restricted flow, as a result of substantial reduction of speed or the rate of flow through a site, is determined essentially by the difference between the arrival rate at the site and the rate at which vehicles are discharged from the bottleneck section. For a given highway section, the arrival rate at the site can be estimated as the average daily traffic volume on the route segment. The rate at which vehicles are released from the site is a function of the traffic management technique employed at that particular site. When the arrival rate exceeds departure rate, a queueing situation can be anticipated. The potential travel delay can be estimated for any given highway segment from an estimate of rate of vehicles joining the queue under conditions of various departure rates resulting from alternative traffic control measures. A comparison of delay times under controlled traffic conditions with historical delays in the absence of control provides the basis for determining the feasibility and potential benefits of a traffic control measure. This section provides a procedure for calculating the average delay per vehicle using ADT rates and estimates of the rate at which vehicles are released from the site for various control measures.

The methodology addresses three levels of traffic control:

- Controlled flow through a site
- Selected route diversion
- Route closure and diversion.

(1) Controlled Flow Through a Site

It is often possible to reduce the recurring hazard created by environmental conditions over specific highway segments by developing and implementing traffic control measures that are directed at maintaining traffic flow through an area at a reduced rate. For example, this may be desirable during periods of snow or mud clearing operations, or under conditions of localized or temporary flooding. In selecting a traffic control measure to counter the hazard to travel created by these conditions, the engineer should assure himself that the control will reduce the potential delay time significantly.

The procedures for calculating the potential delay time at a site are described below. A worksheet (Figure 13) is provided as an aid in completing the calculations. Table 2 contains delay times for various arrival and departure rates and lane conditions. The calculation procedures are:

Line 1: Enter the rate per hour at which vehicles are expected to arrive at the site. If Table 2 is used to compute delay times, this value can be ADT volume. If an hourly rate other than the average hourly rate based on the ADT is used, Table 2 can still be used if this figure is converted to a new ADT.

Line 2: Enter the maximum rate at which vehicles could be discharged through the site under traffic control conditions. A separate worksheet should be prepared for each control measure with a different departure rate.

Line 3: Enter the number of lanes at the highway section under consideration.

Line 4: Enter the average speed of vehicles approaching the bottleneck section. Table 2 assumes an average speed of 55 miles per hour.

Line 5: Enter the estimated duration of the period that travel will be effected over the segment due to adverse environmental conditions.

Line 6: Compute Adjusted Arrival Rate. It is necessary to adjust the arrival rate for the density mix of the traffic. This is accomplished in lines 6.1 and 6.2.

1. Arrival rate _____ veh./hr.

2. Departure rate (under traffic control) _____ veh./hr.

3. Number of lanes at section _____ lanes

4. Average speed of approaching vehicles _____ mph (kph)

5. Anticipated duration of control _____ hrs.

6. Rate of vehicles joining the queue _____ veh./hrs.

   6.1 Density of vehicles in queue _____ veh./mi./lane
   6.2 Adjusted arrival rate (enter on line 6)
   Line l x [1 + (Line 1 - Line 2) ÷
   (Line 3 x Line 4 x Line 6.1 - Line 1)]

7. Number of vehicles in queue during period
   Line 5 x (Line 6 - Line 2) _____ vehs.

8. Average number of vehicles in queue _____ vehs.
   Line 7 ÷ 2

9. Average delay per vehicle _____ hrs.
   [Line 8 ÷ Line 2]

Figure 13. Controlled flow delay time worksheet.

AVERAGE DELAY FOR 4 LANES
PEAK PERIOD (T) = 2.00, BLOCK TIME (R) = 0.00 , SPEED = 55.00

ARRIVAL RATE(/DAY)	DEPARTURE RATE (/HOUR) 250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
8000	0.34	0.11	-0.05	-0.17	-0.26	-0.34	-0.40	-0.45	-0.49	-0.53	-0.56	-0.59	-0.61	-0.64	-0.66	-0.67
13000	1.18	0.82	0.56	0.36	0.21	0.08	-0.02	-0.10	-0.17	-0.23	-0.28	-0.33	-0.37	-0.40	-0.44	-0.47
18000	2.04	1.53	1.17	0.89	0.68	0.51	0.37	0.26	0.16	0.07	0.00	-0.06	-0.12	-0.17	-0.21	-0.26
23000	2.91	2.25	1.79	1.43	1.16	0.94	0.76	0.61	0.49	0.38	0.29	0.20	0.13	0.07	0.01	-0.04
28000	3.79	2.98	2.41	1.98	1.65	1.38	1.16	0.98	0.82	0.69	0.57	0.47	0.38	0.31	0.24	0.17
33000	4.68	3.72	3.04	2.53	2.14	1.82	1.56	1.34	1.16	1.00	0.87	0.75	0.64	0.55	0.46	0.39
38000	5.58	4.47	3.68	3.09	2.63	2.27	1.96	1.71	1.50	1.32	1.16	1.02	0.90	0.79	0.70	0.61
43000	6.49	5.23	4.33	3.66	3.14	2.72	2.37	2.09	1.85	1.64	1.46	1.30	1.17	1.04	0.93	0.83
48000	7.41	6.00	4.99	4.23	3.65	3.17	2.79	2.47	2.20	1.97	1.76	1.59	1.43	1.29	1.17	1.06
53000	8.34	6.77	5.65	4.81	4.16	3.64	3.21	2.85	2.55	2.29	2.07	1.87	1.70	1.55	1.41	1.29
58000	9.28	7.56	6.33	5.40	4.68	4.11	3.64	3.24	2.91	2.63	2.38	2.16	1.97	1.81	1.65	1.52

AVERAGE DELAY FOR 2 LANES
PEAK PERIOD (T) = 2.00, BLOCK TIME (R) = 0.25 , SPEED = 55.00

ARRIVAL RATE(/DAY)	DEPARTURE RATE (/HOUR) 250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
4000	-0.21	-0.33	-0.40	-0.46	-0.51	-0.55	-0.58	-0.60	-0.63	-0.64	-0.66	-0.67	-0.69	-0.70	-0.71	-0.73
9000	0.64	0.38	0.20	0.06	-0.05	-0.13	-0.20	-0.26	-0.31	-0.35	-0.39	-0.42	-0.45	-0.47	-0.48	-0.51
14000	1.50	1.10	0.81	0.60	0.43	0.30	0.19	0.10	0.02	-0.05	-0.10	-0.15	-0.20	-0.24	-0.27	-0.31
19000	2.39	1.84	1.44	1.15	0.92	0.73	0.58	0.46	0.35	0.26	0.18	0.11	0.05	-0.00	-0.05	-0.09
24000	3.30	2.59	2.09	1.71	1.42	1.18	0.99	0.83	0.69	0.58	0.48	0.39	0.31	0.24	0.18	0.13
29000	4.23	3.37	2.75	2.29	1.93	1.64	1.41	1.21	1.05	0.90	0.78	0.67	0.58	0.49	0.42	0.35

AVERAGE DELAY FOR 3 LANES
PEAK PERIOD (T) = 2.00, BLOCK TIME (R) = 0.25 , SPEED = 55.00

ARRIVAL RATE(/DAY)	DEPARTURE RATE (/HOUR) 250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
6000	0.13	-0.04	-0.16	-0.25	-0.33	-0.39	-0.43	-0.46	-0.50	-0.52	-0.55	-0.57	-0.59	-0.60	-0.62	-0.63
11000	0.97	0.66	0.44	0.27	0.14	0.04	-0.04	-0.12	-0.17	-0.23	-0.27	-0.31	-0.34	-0.37	-0.40	-0.43
16000	1.83	1.38	1.05	0.81	0.62	0.47	0.34	0.24	0.15	0.08	.01	-0.05	-0.10	-0.14	-0.18	-0.22
21000	2.71	2.11	1.67	1.35	1.10	0.90	0.74	0.60	0.48	0.38	0.30	0.22	0.16	0.10	0.04	-0.00
26000	3.60	2.84	2.31	1.90	1.59	1.34	1.13	0.96	0.82	0.70	0.59	0.49	0.41	0.34	0.27	0.21
31000	4.50	3.60	2.95	2.47	2.09	1.79	1.54	1.34	1.16	1.01	0.88	0.77	0.67	0.58	0.50	0.43
36000	5.42	4.36	3.60	3.04	2.59	2.24	1.95	1.71	1.51	1.33	1.18	1.05	0.93	0.83	0.74	0.65
41000	6.35	5.13	4.27	3.61	3.11	2.70	2.37	2.10	1.86	1.66	1.49	1.34	1.20	1.08	0.98	0.88

Table 2. Sample delay times.

AVERAGE DELAY FOR 2 LANES
PEAK PERIOD (T) = 2.00, BLOCK TIME (R) = 0.00 , SPEED = 55.00

ARRIVAL RATE(/DAY) \ DEPARTURE RATE (/HOUR)	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
4000	-0.34	-0.45	-0.53	-0.59	-0.64	-0.67	-0.70	-0.73	-0.75	-0.77	-0.78	-0.80	-0.81	-0.82	-0.83	-0.84
9000	0.51	0.26	0.07	-0.06	-0.17	-0.26	-0.32	-0.38	-0.43	-0.47	-0.51	-0.54	-0.57	-0.60	-0.62	-0.64
14000	1.38	0.98	0.69	0.47	0.31	0.17	0.06	-0.03	-0.11	-0.17	-0.23	-0.28	-0.32	-0.36	-0.40	-0.43
19000	2.27	1.71	1.32	1.02	0.79	0.61	0.46	0.33	0.23	0.14	0.06	-0.01	-0.07	-0.13	-0.17	-0.22
24000	3.17	2.47	1.97	1.59	1.29	1.06	0.87	0.71	0.57	0.45	0.35	0.26	0.19	0.12	0.06	0.00
29000	4.11	3.24	2.63	2.16	1.81	1.52	1.28	1.09	0.92	0.78	0.65	0.55	0.45	0.37	0.29	0.22

AVERAGE DELAY FOR 3 LANES
PEAK PERIOD (T) = 2.00, BLOCK TIME (R) = 0.00 , SPEED = 55.00

ARRIVAL RATE(/DAY) \ DEPARTURE RATE (/HOUR)	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
6000	0.00	-0.17	-0.29	-0.38	-0.45	-0.50	-0.55	-0.59	-0.62	-0.65	-0.67	-0.69	-0.71	-0.73	-0.74	-0.76
11000	0.85	0.54	0.31	0.15	0.02	-0.08	-0.17	-0.24	-0.30	-0.35	-0.40	-0.43	-0.47	-0.50	-0.53	-0.55
16000	1.71	1.25	0.93	0.68	0.49	0.34	0.22	0.11	0.03	-0.05	-0.11	-0.17	-0.22	-0.27	-0.31	-0.34
21000	2.58	1.98	1.55	1.23	0.98	0.77	0.61	0.47	0.36	0.26	0.17	0.10	0.03	-0.03	-0.08	-0.13
26000	3.47	2.72	2.18	1.78	1.47	1.22	1.01	0.84	0.69	0.57	0.46	0.37	0.29	0.21	0.15	0.09
31000	4.37	3.47	2.82	2.34	1.96	1.66	1.42	1.21	1.04	0.89	0.76	0.65	0.55	0.46	0.38	0.31
36000	5.29	4.23	3.48	2.91	2.47	2.12	1.83	1.59	1.38	1.21	1.06	0.93	0.81	0.71	0.61	0.53
41000	6.22	5.01	4.14	3.49	2.98	2.58	2.25	1.97	1.74	1.54	1.36	1.21	1.08	0.96	0.85	0.76

AVERAGE DELAY FOR 4 LANES
PEAK PERIOD (T) = 2.00, BLOCK TIME (R) = 0.00 , SPEED = 55.00

ARRIVAL RATE(/DAY) \ DEPARTURE RATE (/HOUR)	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000

Table 2. Sample delay times. (Continued)

AVERAGE DELAY FOR 4 LANES
PEAK PERIOD (T) = 2.00, BLOCK TIME (R) = 0.25 , SPEED = 55.00

ARRIVAL RATE(/DAY)	DEPARTURE RATE (/HOUR) 250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
8000	0.46	0.24	0.08	-0.04	-0.14	-0.21	-0.27	-0.32	-0.37	-0.40	-0.44	-0.46	-0.49	-0.51	-0.53	-0.55
13000	1.31	0.94	0.68	0.48	0.33	0.21	0.11	0.03	-0.04	-0.10	-0.16	-0.20	-0.24	-0.28	-0.31	-0.34
18000	2.17	1.66	1.29	1.02	0.81	0.64	0.50	0.38	0.28	0.20	0.13	0.06	0.00	-0.05	-0.09	-0.13
23000	3.04	2.38	1.91	1.56	1.29	1.07	0.89	0.74	0.61	0.50	0.41	0.33	0.26	0.19	0.13	0.08
28000	3.91	3.11	2.54	2.11	1.77	1.50	1.28	1.10	0.95	0.81	0.70	0.60	0.51	0.43	0.36	0.30
33000	4.80	3.85	3.17	2.66	2.26	1.94	1.68	1.47	1.28	1.13	0.99	0.87	0.77	0.67	0.59	0.51
38000	5.70	4.60	3.81	3.22	2.76	2.39	2.09	1.84	1.63	1.44	1.29	1.15	1.03	0.92	0.82	0.73
43000	6.61	5.36	4.46	3.78	3.26	2.84	2.50	2.21	1.97	1.77	1.59	1.43	1.29	1.17	1.06	0.96
48000	7.53	6.12	5.11	4.36	3.77	3.30	2.92	2.59	2.32	2.09	1.89	1.71	1.56	1.42	1.29	1.18
53000	8.47	6.90	5.78	4.94	4.29	3.76	3.34	2.98	2.68	2.42	2.20	2.00	1.83	1.67	1.54	1.41
58000	9.41	7.68	6.45	5.53	4.81	4.23	3.76	3.37	3.04	2.75	2.51	2.29	2.10	1.93	1.78	1.64

AVERAGE DELAY FOR 2 LANES
PEAK PERIOD (T) = 2.00, BLOCK TIME (R) = 0.50 , SPEED = 55.00

ARRIVAL RATE(/DAY)	DEPARTURE RATE (/HOUR) 250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
4000	-0.09	-0.20	-0.28	-0.34	-0.39	-0.43	-0.45	-0.48	-0.50	-0.52	-0.53	-0.55	-0.56	-0.57	-0.58	-0.59
9000	0.76	0.51	0.32	0.19	0.08	-0.01	-0.07	-0.13	-0.18	-0.22	-0.26	-0.29	-0.32	-0.35	-0.37	-0.39
14000	1.63	1.23	0.94	0.72	0.56	0.42	0.31	0.22	0.14	0.08	0.02	-0.03	-0.07	-0.11	-0.15	-0.18
19000	2.52	1.96	1.57	1.27	1.04	0.86	0.71	0.58	0.48	0.39	0.31	0.24	0.18	0.12	0.08	0.03
24000	3.42	2.72	2.22	1.84	1.54	1.31	1.12	0.96	0.82	0.70	0.60	0.51	0.44	0.37	0.31	0.25
29000	4.36	3.49	2.88	2.41	2.06	1.77	1.53	1.34	1.17	1.03	0.90	0.80	0.70	0.62	0.54	0.47

AVERAGE DELAY FOR 3 LANES
PEAK PERIOD (T) = 2.00, BLOCK TIME (R) = 0.50 , SPEED = 55.00

Table 2. Sample delay times. (Continued)

Line 6.1: Density of vehicles is defined as the number of vehicles at rest, occupying 1 mile of highway at any instant in time. A weighted average is used to account for the varying density of passenger and truck traffic.

For example, if truck traffic accounts for 33% of all traffic on a highway segment, and trucks and passenger cars occupy 50 feet and 22 feet, respectively, the weighted density is given by:

Density = 50' x 1/3 + 22' x 2/3 = 31.33 ft./vehicle

This converts to density in vehicles per mile = 5280/31.33 = 168 vehicles/mile/lane. Enter this density.

Line 6.2: Compute the adjusted arrival rate using the formula provided. Enter this value on Line 6.

Line 7: Compute the estimated number of vehicles in the queue over the duration of the adverse conditions.

Line 8: Compute the average number of vehicles in the queue, which is 1/2 the value of Line 7.

Line 9: Compute the average delay time incurred by vehicles in the queue. This time can also be obtained directly for the entry values shown in Table 2.

(2) Interrupted Flow

The computations described above assume that traffic controls are implemented simultaneously with the onset of the adverse environmental conditions so that there is no halting of the traffic flow, only a reduction in the rate. When the traffic is halted for a temporary period, R, as might be the case when the road must be cleared, the procedure for calculating delay times must be modified. In the case of a temporary road closure, the average number of vehicles in the queue depends upon the length of time the road is closed and the rate at which the traffic is released following the temporary closure. The method of computing the average delay under those conditions is described in the following worksheet (Figure 14).

The procedures for completing the worksheet are provided below:

1. Arrival rate _____ veh./hr.

2. Departure rate (under traffic control) _____ veh./hr.

3. Number of lanes at section _____ lanes

4. Average speed of approaching vehicles _____ mph (kph)

5. Anticipated duration of control _____ hrs.

6. Rate of vehicles joining the queue _____ veh./hrs.

   6.1 Density of vehicles in queue _____ veh./mi./lane

   6.2 Adjusted arrival rate (enter on line 6)
   Line 1 x [1 + (Line 1 – Line 2) ÷
   (Line 3 x Line 4 x Line 6.1 – Line 1)]

7. Number of vehicles in queue during period
   Line 5 x (Line 6 - Line 2) _____ vehs.

8. Duration of temporary road closure _____ hrs.

9. Average number of vehicles in queue _____ vehs.
   [Line 7 + (Line 2 x Line 8)] ÷2

10. Average delay per vehicle _____ hrs.
    [Line 5 x (Line 6/Line 2 – 1) + Line 8] ÷2

Figure 14. Interrupted flow delay time worksheet.

Line 1: Enter the per hour rate at which vehicles are expected to arrive at the site. If Table 2 is used to compute delay times, this value can be ADT volume. If an hourly rate other than the average hourly rate based on the ADT is used, Table 2 can still be used if this figure is converted to a new ADT.

Line 2: Enter the maximum rate at which vehicles could be discharged through the site under traffic control conditions. A separate worksheet should be prepared for each control measure with a different departure rate.

Line 3: Enter the number of lanes at the highway section under consideration.

Line 4: Enter the average speed of vehicles approaching the bottleneck section.

Line 5: Enter the estimated duration of the period that travel will be effected over the segment due to adverse environmental conditions.

Line 6: Compute Adjusted Arrival Rate. It is necessary to adjust the arrival rate for the density mix of the traffic. This is accomplished in Lines 6.1 and 6.2.

Line 6.1: Enter the density of vehicles occupying 1 mile of highway at any instant in time. A weighted average is used to account for the varying density of passenger and truck traffic (see previous procedures for an example).

Line 6.2: Compute the adjusted arrival rate using the formula provided. Enter this value on Line 6.

Line 7: Compute the estimated number of vehicles in the queue over the duration of the adverse conditions.

Line 8: Enter the duration of the expected traffic halt.

Line 9: Compute the average number of vehicles in the queue, which is 1/2 the value of Line 7.

Line 10: Compute the average delay time incurred by vehicles in the queue. This time can also be obtained directly for the entry values shown in Table 2.

(3) Selected Route Diversion

The need for restriction of travel on limited access highways by a specific vehicle class arises occasionally. Most often it occurs as a result of high wind conditions when it may be necessary to divert trailer trucks, mobile homes or other high profile vehicles to other primary or secondary roads. The basic difference in examining selective route diversion of specific classes of highway users as an alternative to controlled flow through a site is that an additional delay is incurred by the diverted traffic due to increased travel time over the alternate route. For the diverted traffic, the delay is estimated as the sum of the average time spent in queue and the additional time required to travel through the alternate route. In this case, the traffic control measures applied in the diversion of classes of highway users and the control of traffic flow through the hazardous area can have a significant effect on the average delay incurred by the highway users.

If queuing is expected to occur as a result of the selective route diversion control, the delay time can be estimated for the appropriate vehicle classes using the method described for controlled traffic flow. The total delay per vehicle that is diverted through alternate route is given by:

Total delay = Average delay per vehicle + estimated increased travel time over detour route.

For the traffic that is not diverted, the average delay is simply the delay associated with queueing resulting from controlled flow through site.

The procedure involved in computing the average delay per vehicle that is not diverted and the total delay per vehicle that is diverted over an alternate route is presented in the following worksheet (Figure 15). Instructions for completing the worksheet are given below:

Line 1: Estimate the arrival rate of vehicles on a given highway segment, using average daily traffic volume. Compute the weighted average daily traffic volume using the appropriate percentage distribution of trucks and passenger vehicles at that site. If, for example, heavy trucks account for 1/3 of the traffic

1. **Arrival rate**

   1.1 Arrival rate of vehicle traffic to be diverted _____ veh/hr.
   1.2 Arrival rate of through traffic _____ veh./hr.

2. **Departure rate**

   2.1 Departure rate of diverted traffic _____ veh./hr.
   2.2 Departure rate of through traffic _____ veh./hr.

3. **Number of lanes**

   3.1 Lanes assigned to diverted traffic _____ lanes
   3.2 Lanes assigned to through traffic _____ lanes

4. **Average speed of approaching vehicles** _____ **mph (kph)**

5. **Anticipated duration of control** _____ **hrs.**

6. **Adjusted arrival rate**

   6.1 Density of diverted vehicles _____ veh./mile/lane
   6.2 Density of through vehicles _____ veh./mile/lane
   6.3 Adjusted arrival rate of diverted vehicles
   Line 1.1 x [1 + (Line 1.1 — Line 2.1) ÷ (Line 3.1 x Line 4 x Line 6.1 — Line 1.1)] _____ veh./hr.
   6.4 Adjusted arrival rate of through vehicles
   Line 1.2 x [1 + (Line 1.2 - Line 2.2) ÷ (Line 3.2 x Line 4 x Line 6.2 —Line 1.2)] _____ veh./hr.

7. **Average number of vehicles**

   7.1 Average number of diverted vehicles _____ vehs.
   [Line 5 x (Line 6.3 - Line 2.1)] ÷ 2
   7.2 Average number of through vehicles _____ vehs.
   [Line 5 x (Line 6.4 - Line 2.2)] ÷ 2

8. **Delay time for through vehicles** _____ **hrs.**
   Line 7.2 ÷ Line 2.2

9. **Additional travel time over alternate route** _____ **hrs.**

10. **Delay incurred by diverted vehicles** _____
    (Line 7.1 ÷ Line 2.1) + Line 9

Figure 15. Selective route diversion delay time worksheet.

on a highway with an average daily traffic volume of 30,000 then the arrival rate for trucks is:

Average Arrival Rate (heavy vehicles) = 30,000 x 1/3
= 10,000
trucks/day

and, Average Arrival Rate of passenger cars = 30,000 x 2/3
= 20,000
cars/day.

Line 1.1: Enter the arrival rate of the class of vehicles to be diverted in vehicles/hour. This may be the average hourly rate based upon the daily rate calculated above. It is recommended, however, that traffic count data be used to estimate the number of vehicles if the delay is to be calculated on the basis of the peak hour rate.

Line 1.2: Enter the rate of arrivals of the class of vehicles that will not be diverted in vehicles/hour. Use same basis as used in completing Line 1.1.

Line 2: Estimate the departure rates associated with controlled flow through site and for the classes of vehicles diverted to an alternate route.

Line 2.1: Enter the departure rate associated with the diverted traffic.

Line 2.2: Enter the rate of which vehicles are released from the control section.

Line 3: Estimate the number of highway lanes that will be used by both types of vehicles.

Line 3.1: Enter the number of lanes in which traffic to be diverted will be restricted to as it approaches the diversion point.

Line 3.2: Enter the number of lanes dedicated to through traffic approaching the diversion point.

Line 4: Enter the average speed of vehicles approaching the control section.

Line 5: Indicate the duration of adverse weather conditions, or the period of selected diversion.

Line 6: Compute the rate at which vehicles join the queue, using the estimates of density for the mix of diverted vehicles and through vehicles, the arrival and departure rates, and the number of lanes on the section.

Line 6.1: Enter the density of diverted vehicles in number of vehicles per mile. If a diverted vehicle occupies 50 feet then the density is given by:

Density of diverted vehicles = 5,280 ÷ 50 = 106

Line 6.2: Enter the density of through vehicles in number per mile. For a typical through vehicle such as a passenger car occupying 22 feet this density is 5,280 ÷ 22 = 240 vehicles/mile.

Line 6.3: Compute the adjusted arrival rate of diverted vehicles using the previously determined arrival and departure rates.

Line 6.4: Compute the adjusted arrival rate of through vehicles using the previously determined arrival and departure rates.

Line 7: Compute the average number of vehicles of each type in the queue.

Line 7.1: Compute the average number of diverted vehicles in the queue.

Line 7.2: Compute the average number of through vehicles in the queue.

Line 8: Compute the average delay to vehicles that are not diverted using the formula presented in worksheet, or using the table provided in the manual.

Line 9: Enter the time required for diverted vehicles to travel through the alternate route. This estimate is based on the traffic engineer's selection of an alternate route from among various routes.

Line 10: Compute the average delay to vehicles that are diverted, using the formula provided in worksheet.

(4) Road Closure and Diversion

The principal effect of road closure is the increase in journey time on the alternate route. The

average delay is the sum of the time spent in the queue at the hazardous location and the additional time required to travel through the alternate route. For given arrival rate and departure rate, the average time spent in the queue can be obtained as described in the initial worksheet (Figure 14). The average delay per vehicle is given by:

Average Delay = Time spent in queue + additional time required to travel through alternate route.

The time spent in queue can also be obtained from Table 2 for specific arrival and departure rates.

4. SELECTION OF A DELAY REDUCTION TRAFFIC CONTROL

The procedures described in the previous section will enable the traffic engineer to estimate the delay time that will be incurred by highway users as a result of implementation of a traffic control on a limited access highway. In some instances, it is anticipated that there will only be one appropriate control measure under consideration. Implementation of that traffic control is warranted if the control will result in a significant reduction in the delay that would occur if no control were implemented.

Often, however, it is expected that several alternative control measures will be under consideration. In these cases, selection of the most appropriate control is usually complicated by non-proportional differences in the relative cost and effectiveness of these controls. The following procedures describe a method for selecting the most appropriate control using the traffic control costs and delay times previously determined by following the procedures presented earlier in this chapter. The selection procedures are:

(1) For a given highway segment, determine average delay times associated with each alternative traffic control using the table presented in this manual or the formula presented in each of the control evaluation worksheets.

(2) Using delay time as the unit of effectiveness, compute the average annual reduction of delay time. This is done by comparing the delay time associated with each control with the delay expected to result if no controls are implemented.

(3) List the improvements in order of increasing Equivalent Uniform Annual Cost as determined in the Cost Estimating Worksheet (Figure 11).

(4) Beginning with the alternative control measure having the second lowest cost, and continuing in order of increasing costs, calculate the incremental cost/effectiveness for each alternative control measure compared to the "best cost" traffic control. Initially, the control having the lowest cost is defined as the "best cost" traffic control. The calculation steps are as follows:

- Calculate the incremental cost/incremental effectiveness ratio (IC/IE) for the control under consideration compared to the control having the lowest cost. For example, the ratio for comparing the control having the second lowest cost with the control having the lowest cost is:

$$IC/IE = \frac{C_2 - C_1}{E_2 - E_1} \quad \text{where}$$

C_1 = Cost of lowest cost control

C_2 = Cost of next lowest cost control

E_1 = Benefits of lowest cost control (in hours)

E_2 = Benefits of next lowest cost control (in hours)

- If the cost per unit of additional effectiveness is deemed justifiable, the control under consideration becomes the most cost-effective control to implement -- the new "best cost" traffic control. Otherwise, the lowest cost control remains the "best cost" traffic control.

(5) After the calculations performed in procedure (4) are complete for each alternative traffic control measure, select the "best cost" traffic control for implementation.

5. SELECTION OF AN ACCIDENT REDUCTION CONTROL

If the effectiveness of specific traffic controls in reducing accidents were known, the selection of an appropriate measure could be based upon a traditional cost

effectiveness approach. Each proposed control measure could be examined in terms of the incremental effectiveness achieved for the next increment of cost. At present, reliable data on the effectiveness of traffic controls is not available. In the absence of this data, the selection of appropriate traffic controls will have to rely on an approach that is not dependent upon established levels of effectiveness.

The approach suggested in these guidelines is based on a cost-effectiveness methodology. Instead of relying on an effectiveness measure, however, in order to determine the cost effectiveness of a traffic control, a method is described for calculating the effectiveness that would have to be achieved by a control in order to be cost effective. It is left to the judgement of the engineer to decide if the proposed control has the potential for achieving the necessary level of effectiveness, i.e., is it likely that it will reduce the accident rate by the required percentage?

(1) Data Requirements

The data required for analyzing traffic controls and determining if a control is justifiable, and if so, which one are described below:

- Accident rate at location (from Incident Analysis Worksheet)
- Projected traffic volume for each year or period over the expected life of the control
- Equivalent Uniform Annual Cost of the proposed traffic control (from the Cost Estimating Worksheet)
- An estimate of the costs per accident which may be a composite of fatal and non-fatal accident cost estimates or separate estimates depending upon the categories used for statement of the accident rates.

From this information, the percentage reduction in accidents that must be accomplished by a traffic control can be determined. The potential of the control for achieving this level of reduction is then reviewed for reasonableness. Based upon that test the traffic control can be either selected or rejected as a solution.

The procedures for performing the analysis of control effectiveness are described in the following section.

(2) Effectiveness Evaluation

The procedures provided in this section describes a method for determining the percent reduction in accident rates that a traffic control should achieve in order to be cost effective. This reduction rate represents the minimal effectiveness level of a control which is acceptable for controls proposed for installation.

The minimal effectiveness rate is determined by dividing the cost of implementing a control over its expected life span by the total cost of accidents that would occur during that same period if no control were implemented. The cost of the control is the Equivalent Uniform Annual Cost calculated previously. In estimating the cost of accidents, it is assumed that the accident rate at the location will remain constant.

The number of accidents in future periods may, of course, increase as traffic volume at the location increases. The cost of accidents for the period is estimated by multiplying the expected number of accidents for each year in the period times the cost of an accident. The quality of the accident cost estimates derived in this way do not warrant concern with inflationary effects because they would be cancelled out largely by the need to discount these costs back to a present value. The present value of accident costs for the period, therefore, can be assumed to be the sum of the annual accident costs for the period. These costs represent the present value of the total benefits that could accrue if the accident rate were reduced to zero over the period.

If the cost of a proposed control in current dollars is divided by the total benefits that could be incurred, the resulting ratio is a statement of the minimal accident reduction rate (in percent) that should be achieved by the control to be cost-effective. This reduction rates can then be examined first to determine if the control is justified in terms of the cost of implementing the control. A comparison can also be made among controls on the basis of cost and effectiveness ratios to select the control which

provides the most reasonable solution as an accident reduction measure.

The procedures for completing this analysis are described below. A worksheet (Figure 16) has been provided as an aid in performing this analysis.

Line 1: Enter expected service life of traffic control. Use one year for procedural controls involving temporary assignment of personnel and equipment.

Line 2: Enter accident rate for location from Incident Analysis Worksheet.

Line 3: Estimate projected traffic volume for each year of control period and sum.

Line 4: Multiply traffic volume total times accident rates for each category determined.

Line 5: Enter cost of accidents from estimates based upon composite accident rate or separately for those involving fatalities, injuries, and property damage only.

Line 6: Estimate total accident costs for period by multiplying composite costs or separate costs for accidents times the expected number in each category.

Line 7: Enter the Equivalent Uniform Annual Cost from the Cost Estimating Worksheet for the control being considered for implementation.

Line 8: Calculate the minimum effectiveness ratio by dividing Line 7 by Line 6.

The results of this analysis indicate the minimum reduction in accident rates that should be accomplished by the traffic control in order to be cost effective. It should be made clear that this ratio is not the level of effectiveness that will be achieved by the control. Instead, it is that level of effectiveness that must be achieved as a minimum to justify implementing the control from the standpoint of cost-effectiveness.

While the analysis does not provide a precise solution, it does provide an order of magnitude evaluation measure that can be useful in confirming

LOCATION:

TRAFFIC CONTROL DESCRIPTION

1. Estimated service life of control: _____ years

2. Accident rate at location _____ /MVM

3. Estimated total traffic volume in period _____ MV

4. Estimated number of accidents

   Fatalities _____
   Injuries _____
   Property damage only _____

5. Cost per accident $_____

   Fatal $ _____
   Injury $ _____
   PDO $ _____

6. Total accident costs at location during period $ _____

   (Line 4 x Line 5)

7. Equivalent Uniform Annual Cost of Control $ _____

8. Minimum reduction effectiveness ratio _____ %

   [(Line 7 ÷ Line 6 x 100)]

Figure 16. Accident reduction control analysis worksheet.

the need for, and selecting traffic control measures. As an aid to understanding and using this approach a series of example worksheets have been provided in Figures 17-22.

TRAFFIC CONTROL II

1.	INITIAL COST	$ 8000
2.	SERVICE LIFE OF EQUIPMENT	10
3.	ANNUAL OPERATING	10
4.	MAINTENANCE COSTS	90
5.	TERMINAL VALUE	0
6.	INTEREST RATE 10 %	
7.	CAPITAL RECOVERY FACTOR (FROM TABLE 2 OR EQUIVALENT)	.16275
8.	SINKING FUND FACTOR (FROM TABLE 2 OR EQUIVALENT)	.06275
9.	EQUIVALENT UNIFROM ANNUAL COST (LINE 1 x LINE 7 + LINE 3 + LINE 4 – LINE 5 x LINE 8)	$ 1402

Figure 17. Cost estimating worksheet.

1. Arrival rate ___334___ veh./hr.

2. Departure rate (under traffic control) ___300___ veh./hr.

3. Number of lanes at section ___4___ lanes

4. Average speed of approaching vehicles ___55___ mph (kph)

5. Anticipated duration of control ___2___ hrs.

6. Rate of vehicles joining the queue ___334.3___ veh./hrs.

   6.1 Density of vehicles in queue ___168___ veh./mi./lane

   6.2 Adjusted arrival rate (enter on line 6)
   Line I x [1 + (Line 1 - Line 2) ÷
   (Line 3 x Line 4 x Line 6.1 - Line 1)]

7. Number of vehicles in queue during period
   Line 5 x (Line 6 - Line 2) ___68.6___ vehs.

8. Average number of vehicles in queue ___34.3___ vehs.
   Line 7 ÷ 2

9. Average delay per vehicle ___.114___ hrs.
   [Line 8 ÷ Line 2]

Figure 18. Controlled flow delay time worksheet.

1. Arrival rate 334 veh./hr.

2. Departure rate (under traffic control) 320 veh./hr.

3. Number of lanes at section 4 lanes

4. Average speed of approaching vehicles 55 mph (kph)

5. Anticipated duration of control 2 hrs.

6. Rate of vehicles joining the queue 334 veh./hrs.

   6.1 Density of vehicles in queue 168 veh./mi./lane

   6.2 Adjusted arrival rate (enter on line 6)
   Line 1 x [1 + (Line 1 − Line 2) ÷
   (Line 3 x Line 4 x Line 6.1 − Line 1)]

7. Number of vehicles in queue during period
   Line 5 x (Line 6 - Line 2) 28 vehs.

8. Duration of temporary road closure 1/2 hrs.

9. Average number of vehicles in queue 188 vehs.
   [Line 7 + (Line 2 x Line 8)] ÷2

10. Average delay per vehicle .588 hrs.
    [Line 5 x (Line 6/Line 2 − 1) + Line 8] ÷2

Figure 19. Interrupted flow delay time worksheet.

1. Arrival rate

   1.1 Arrival rate of vehicle traffic to be diverted — 111 veh/hr.
   1.2 Arrival rate of through traffic — 223 veh./hr.

2. Departure rate

   2.1 Departure rate of diverted traffic — 100 veh./hr.
   2.2 Departure rate of through traffic — 120 veh./hr.

3. Number of lanes

   3.1 Lanes assigned to diverted traffic — 1 lanes
   3.2 Lanes assigned to through traffic — 3 lanes

4. Average speed of approaching vehicles — 55 mph (kph)

5. Anticipated duration of control — 2 hrs.

6. Adjusted arrival rate

   6.1 Density of diverted vehicles — 106 veh./mile/lane (veh./km/lane)
   6.2 Density of through vehicles — 240 veh./mile/lane (veh./km/lane)
   6.3 Adjusted arrival rate of diverted vehicles
   Line 1.1 x [1 + (Line 1.1 – Line 2.1) ÷ (Line 3.1 x Line 4 x Line 6.1 – Line 1.1)] — 111.2 veh./hr.
   6.4 Adjusted arrival rate of through vehicles
   Line 1.2 x [1 + (Line 1.2 - Line 2.2) ÷ (Line 3.2 x Line 4 x Line 6.2 –Line 1.2)] — 223 veh./hr.

7. Average number of vehicles

   7.1 Average number of diverted vehicles [Line 5 x (Line 6.3 - Line 2.1)] ÷ 2 — 11.2 vehs.
   7.2 Average number of through vehicles [Line 5 x (Line 6.4 - Line 2.2)] ÷ 2 — 103 vehs.

8. Delay time for through vehicles Line 7.2 ÷ Line 2.2 — .86 hrs.

9. Additional travel time over alternate route — .3 hrs.

10. Delay incurred by diverted vehicles (Line 7.1 ÷ Line 2.1) + Line 9 — .412 HRS.

Figure 20. Selective route diversion delay time worksheet.

LOCATION:

TRAFFIC CONTROL DESCRIPTION

1. Estimated service life of control: 10 years

2. Accident rate at location 37 /MVM (MVkm)

3. Estimated total traffic volume in period 4.0 MV

4. Estimated number of accidents

   Fatalities 4
   Injuries 26
   Property damage only 7

5. Cost per accident $_____

   Fatal $ 82,000
   Injury $ 3,400
   PDO $ 400

6. Total accident costs at location during period $ 419,760

   (Line 4 x Line 5)

7. Equivalent Uniform Annual Cost of Control $ 1402

8. Minimum reduction effectiveness ratio .334 %

   [(Line 7 ÷ Line 6 x 100)]

Figure 21. Accident reduction control analysis worksheet.

Level of Control	I	II	III	IV	V
1. Departure Rate	100.000	300.000	320.000	110.000	300.000
2. Average Delay Times	2.350	.114	.588	.636	.414
3. Average Annual Reduction of Delay Times		2.240	1.760	1.710	1.940
4. Equivalent Uniform Annual Cost	$500	$1402	$1000	$800	$1200

PRIORITY IMPROVEMENTS

Improvements EVAC	Annual Reduction of Delay Times	Annual Reduction of Delay Times
1. Implementing No Control—I	$500	—0—
2. Selected Route Diversion—IV	$800	1.71
3. Interrupted Flow—III	$1000	1.76
4. Road Closure—V	$1200	1.94
5. Controlled Flow—II	$1402	2.24

Figure 22. Delay reduction control analysis worksheet. (Example)

V. TRAFFIC CONTROL EFFECTIVENESS DETERMINATION

The basic approach to evaluation and selection of traffic control procedures described in the previous chapter of this manual was chosen because of the lack of reliable data on the effectiveness and cost of specific traffic control measures. If data on the effectiveness of various measures in reducing accident rates or travel delays were available, along with information on the cost of implementing these controls, selection of a control for a given situation could be based upon a straightforward cost-effectiveness analysis. This chapter describes the information that would be required for a more rigorous evaluation of traffic control effectiveness and the analytical procedures that should be followed in performing that analysis.

1. DATA REQUIREMENTS

The anticipated increased reliance on traffic control measures to reduce hazards created by adverse environmental conditions will generate a need for improved information on the relative effectiveness of various control measures to aid in the selection of the most appropriate solution. The information required is not currently available. It is recommended that transportation agencies begin to accumulate this information as an aid to both the current and the future analysis of traffic control measures.

The general categories of data required for evaluation of the effectiveness of traffic controls in reducing the hazards created by adverse environmental conditions include those describing:

- Environmental conditions
- Accidents
- Traffic delays
- Traffic control costs
- Traffic volume.

Most of the data in these categories that is required for evaluation of traffic controls is readily available, but is not currently collected or maintained in a manner that

is suitable for analysis. Also, since the recommended approach to evaluating effectiveness is a "before-after" analysis of accident or delay frequencies, some of the data required will be of a historical nature. This will require accumulating data for at least one year prior to installation of the control -- preferably, for several years preceding the control. The type of data and suggested sources are described below.

(1) Environmental Conditions

The first step in the development of an evaluation program for special traffic controls should be collection and maintenance of information on the frequency and severity of specific environmental conditions within specific geographic sectors. At a minimum, this information should indicate the frequency of occurrence to permit better estimates of the exposure levels and accident rates associated with these conditions. National and local weather reports for the sectors traversed by the highway system are the most readily available sources of this data.

Additional information on environmental conditions can significantly improve the precision of the analysis of hazardous locations and traffic control effectiveness. Expanding the level of detail of the environmental information will require obtaining data on specific sites, generally, from maintenance or law enforcement personnel. The information contained in these site reports might include:

- Time of day
- Type and duration of condition
- Severity of condition
- Estimated traffic volume
- Driver reactions to hazardous condition.

(2) Accidents

The accident reporting forms commonly in use in most states provide for collection of most of the information required for reliable estimates of the effect of environmental conditions on accident frequency. In many instances, however, this information

is not extracted and reviewed in a manner that would be useful in determining the need for traffic controls under various conditions. In other instances, information that would be useful in determining the severity of conditions (e.g. fog visibility distance, snow depth on travelled way) could be added to existing forms with very little difficulty. Often, there are problems associated with the reliability and consistency of the data provided in the field reports. The validity of the accident data will become more apparent with increased reliance on this information for analytical purposes. Including law enforcement planning officers in the analysis of accident and hazard data may provide the support required for educating and gaining the cooperation of field personnel in improving the accident reporting process.

(3) Traffic Delays

As in the case of accident reporting, the information required for analysis of traffic delays can be obtained with relative ease, but it is not collected in a coordinated or systematic fashion. Most states do not require the routine reporting of information on incidents resulting in traffic delays. That information would be useful in determining the nature and extent of recurring problems. Law enforcement personnel will generally include the information in their shift reports, and this source can be a useful one, if it is accessible to the transportation agency. Maintenance and district engineering personnel, if they are involved in providing assistance, will provide information on some delays.

Developing the capability to identify and treat recurring traffic delay conditions, therefore, will require establishment or improvement of reporting procedures to provide data, such as:

- Nature and severity of environmental conditions
- Time of day and duration of delay
- Estimated traffic volume
- Traffic control action taken

. Number and type of personnel assigned.

(4) Traffic Control Costs

The cost of implementing a traffic control measure is a major determinant in the selection and justification of a proposed action. At present, the only readily available data on traffic control costs are those associated with the initial purchase prices for the required traffic control devices and related hardware. However, adequate evaluation of the cost-effectiveness of various measures requires that information be available on the installation, operation and maintenance costs associated with each alternative traffic control device or program. A major component of the cost of implementation may be personnel costs and these should be recorded, particularly if these costs involve overtime labor rates. Collecting this information may require assembly of data from several sources. The procedures for collecting this information should be initiated at the same time that a traffic control program or device is installed to assure proper accumulation of these costs.

(5) Traffic Volume

Assessments of the need for and effectiveness of traffic control measures are very sensitive to the traffic volume estimates used in establishing incident rates. Although current Average Daily Traffic (ADT) figures can be obtained readily for limited access highways, they can only provide gross measures of the numbers of vehicles exposed to hazardous conditions. Although these estimates will suffice for the analytical approach described in the previous chapters, the accuracy of the evaluation results can be improved significantly with the use of more precise data. As a minimum, therefore, it is recommended that traffic count data be obtained for locations under consideration for traffic control implementation to provide reliable estimates of exposure levels. The sample of traffic data should be sufficiently large to permit development of a profile of traffic volume based upon time of day, day of the week, and season of the year, if appropriate.

If the data included in these categories is collected and maintained in an organized fashion, the traffic engineer will be able to analyze and develop very reliable estimates of the effectiveness of any

traffic control measures. The basic approach to traffic control evaluation is described in the following section. The methodology described is comparable to that described in the previous chapter, but follows a more straightforward approach to evaluation because of reliance on availability of more complete and detailed information.

2. ANALYSIS REQUIREMENTS

If the data described in the preceding section is available, the determination of the effectiveness of a special control measure is a relatively simple process. The basic approach described in this section is based upon a "before-after" analysis of the incident rates at a traffic control location.

The data elements required for the analysis include:

- Type and period/frequency of traffic control implementation
- Before and after incident characteristics at location
  - number of delays
  - number of accidents
    - .. fatalities
    - .. injuries
    - .. property damage only
- number of times adverse environmental conditions present
- ADT or traffic count during adverse and non-adverse conditions.

The procedures for determining the effectiveness of a traffic control measure are described below. The procedures described are for analysis of accident rates. A comparable analysis of delay incidents can be made using the same procedures, where an incident is defined as a delay which has a duration greater than some minimum value (e.g., 15 minutes).

(1) For each hazardous location, identify the number and severity of accidents or incidents in the time period before and after the implementation of a traffic control. The length of the before-implementation time period selected should be comparable to the after-implementation time period.

(2) Compute the incident rates before and after the implementation of a traffic control. Make adjustments if necessary to reflect differences in traffic volumes and time periods as follows:

If the period is in days and the difference in the length of the before and after time period is only a few days, then the number of accidents before the implementation is given by:

$$B' = \frac{B \text{ (After ADT) (Days in after period)}}{\text{(Before ADT) (Days in before period)}}$$

where

B' = adjusted number of accidents to be used in determining rate

B = number of accidents before implementation.

If there is a significant difference in time periods, then an average value should be used for comparison purposes. If the traffic volume changes during the before or after period, then the ADT should be prorated over each of the periods of different volume to obtain an annual average traffic volume. Once the adjustments are made, compute the accident rates using the formulas provided in the preceding chapters.

(3) Compute the percent reduction at the location using the formula:

$$\text{Percent Reduction} = \frac{100 \text{ [Acc. Rate After - Acc. Rate Before]}}{\text{Acc. Rate Before}}$$

(4) Refer to the curves in Figure 23 and locate the point of intersection of the number of accidents before implementation and the percent reduction. The curves in this figure are used to examine the significance of the accident rate reduction due to the implementation of the traffic control measure. The upper curve depicts the Poisson Distribution Test, and the lower curve depicts the Poisson Comparison of Means Test.

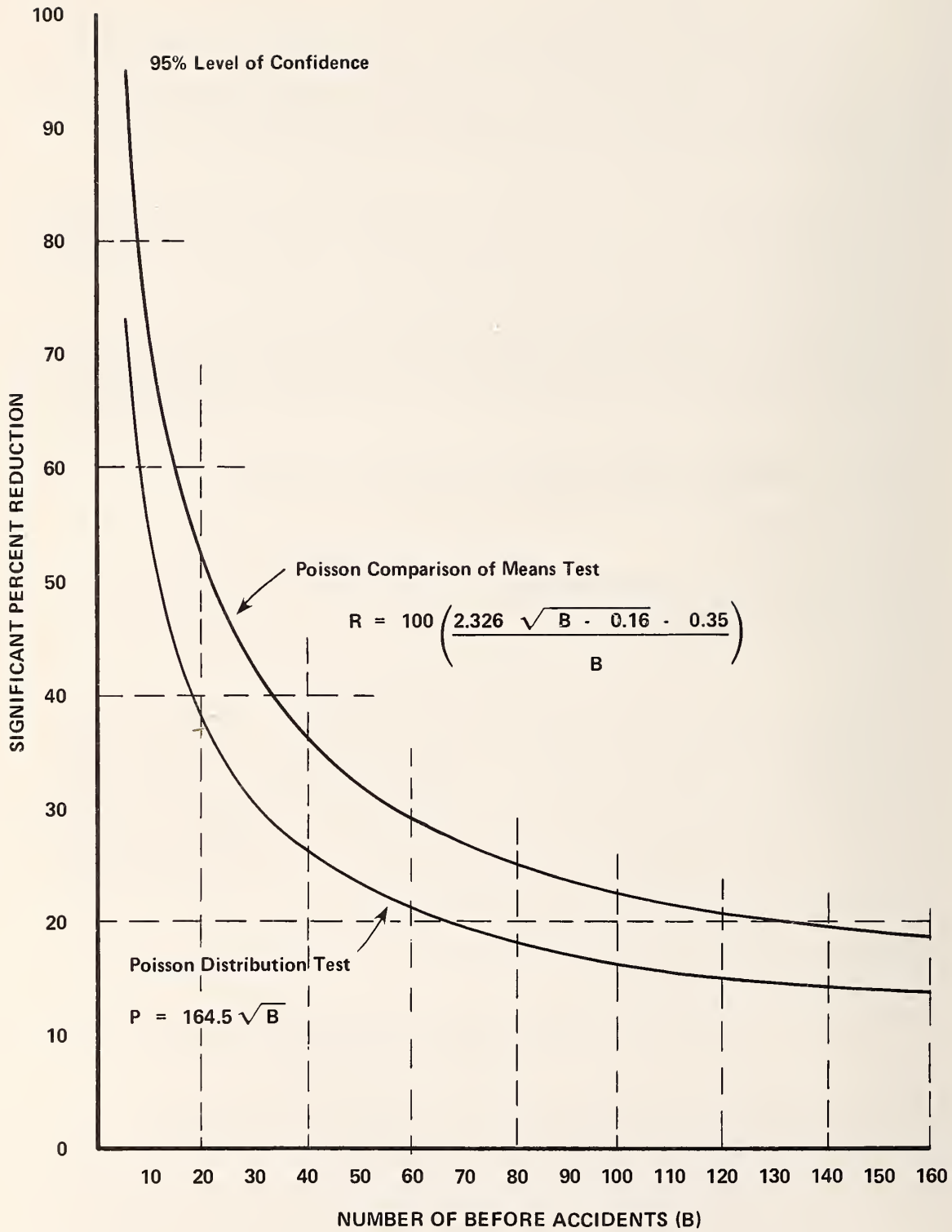

Figure 23. Poisson Tests for Significance.

The significance of the percent reduction is determined in the following manner:

For the Poisson Distribution Test, the test value is

$$R_1 = 164.5\sqrt{B}$$

For the Poisson Comparison of Means Test, the test value is

$$R = 100\ \frac{(2.326\sqrt{B-.16} - .35)}{B}$$

Where:

B = Number of accidents before the implementation.

These values are based upon 95% level of confidence.

(5) If the actual reduction of the accident rate exceeds the test values (R and R_1) for both tests, then the results are significant and, it can be concluded that the reduction is attributable to the traffic control measure.

(6) If the actual rate of reduction is less than the minimum of the test values (R and R_1) for both tests, then the results are considered insignificant. Thus, it is concluded that the accident reduction is not directly attributable to the control measure.

(7) If the actual rate falls in between the values (R and R_1) for both tests, then the significance of the results is uncertain. When this situation is encountered, the analyst should collect reliable data for an additional period of time, and then re-evaluate the effectiveness of the traffic control.

(8) Repeat the process for evaluation of the effectiveness of the control in reducing the severity of accidents using data on fatal and non-fatal accidents.

The effectiveness of various traffic controls measured in terms of the percentage of accident reduction and the significance of the reduction, should be recorded and maintained for future reference. This information on the relative effectiveness of control measures will be of

considerable assistance in the future selection of controls for comparable installations. Figure 24 on the following page suggests a format for maintaining data on traffic control effectiveness.

ENVIRONMENTAL CONDITION INCIDENT ANALYSIS
WORKSHEET

1. LOCATION (STATE/ROUTE/SEGMENT):

Intersection | Spot | Section | Section Length

2. CATEGORY:

Rural	4 – Lane	Interstate
Urban	6 – Lane	Other Limited Access
	– Lane	

3. ENVIRONMENTAL CONDITION:

Fog | Snow | Flood
Dust/Sand | Ice | Wind
Other (Indicate) _____
Number of Days/Times Condition Occurred in Period _____
Severity and Frequency:
No. of Days/Times Extreme Conditions (Define)_____.
No. of Days/Times Severe Conditions (Define) _____.
No. of Days/Times Moderate Conditions (Define)_____.

4. ACCIDENT EXPERIENCE:

	BEFORE			AFTER		
	YEAR 19__	YEAR 19__	YEAR 19__	YEAR 19__	YEAR 19__	YEAR 19__
From (Date)						
To (Date)						
AADT						
Total Accidents						
Fatal Accidents						
No. Fatalities						
Injury Accidents						
PDO Accidents						
Accident Rate						
Reduction %						

5. SYSTEMWIDE AVG. RATE FOR CATEGORY: _____ Acc/MV

6. RATE FOR CATEGORY AND CONDITION: _____ Acc/Condition Days

Figure 24. Incident and Effectiveness evaluation worksheet.

APPENDIX A

ILLUSTRATIVE TRAFFIC CONTROL MEASURES

1. TRAFFIC CONTROL: Operation Fogbound

2. ENVIRONMENTAL CONDITION: Fog

3. IMPLEMENTING STATE: California

4. OPERATING STATUS AND YEARS IN OPERATION: Currently operational; in effect since 1970.

5. AVERAGE DAILY TRAFFIC VOLUME: Interstate 5-8000/8500 - 9000 (1975); Route 99-22000/30000 (1974); 24000/30000 (1975).

6. DESCRIPTION: Operation Fogbound has been effective in minimizing traffic accidents during fog conditions. The program includes identification and analysis of fog accidents, public education, engineering, training, enforcement, traffic control, and evaluation.

   . Public Education

   The activities that relate primarily to educating the public include

   - Soliciting Radio and T.V. cooperation
   - Handing out leaflets at trucks stops, restaurants, etc.
   - Initiating SIGALERT message broadcast series to keep the public alerted to fog conditions. This service provides information regarding traffic movement and congestion, closed thoroughfares and alternate routes, unusual weather conditions etc.

   . Traffic Control

   The basic procedure to control traffic during fog conditions is as follows:

- When maximum visibility is reduced to 400 feet, patrol units with appropriate magnetic signs are deployed to predetermined beats, with their primary role being traffic control.

- When maximum visibility drops to less than 250 feet, all phases of Operation Fogbound are initiated. A procedure called 'Round Robin' is implemented. During "round robin" a patrol unit will enter the freeway with lights flashing and control the speed of following vehicles. As he approaches the end of his beat, he will leave the freeway via an off-ramp, cross the freeway and re-enter the freeway via an on-ramp and proceed with his traffic control procedure in the opposite direction. The fog beats are pre-determined. Officers are deployed so that their areas of responsibility do not overlap and they remain in view and on patrol at all times.

  The enforcement stops for minor violations are minimized during Operation Fogbound. Only potentially dangerous violations such as speeding and driving without headlights warrant a stop in the fog.

. Training

  Prior to the fog season officers participating in Operation Fogbound Program receive training on the round robin convoy techniques and operational aspects of Operation Fogbound.

7. INSTALLATION COST: Some unidentified costs have been incurred for magnetic and trunk mounted signs for use on CHP vehicles. Signs are not considered effective.

8. ANNUAL OPERATING AND MAINTENANCE: No estimates available.

1. TRAFFIC CONTROL: Motorist Advisory System

2. ENVIRONMENTAL CONDITIONS: Ice Frost and Fog

3. IMPLEMENTING STATE: Illinois

4. OPERATING STATUS AND YEARS IN OPERATION: One year of test data on two bridges.

5. AVERAGE DAILY TRAFFIC (ADT) VOLUME: Not available.

6. DESCRIPTION: The system consists of moisture ice and structure/air temperature detectors which are in pairs on test bridges. When both detectors indicate the same alarm (water, alert or ice), a digital signal is encoded or decoded. A dispatcher reviews the digital messages and deploys, via radio, maintenance personnel to check condition and spread sound/deploy flip-up signs. The warning signs are located 600 feet in advance of the structure to give ample warning of the upcoming hazard.

7. INSTALLATION COST: The cost is estimated for a simple 4-lane divided location consisting of two separate structures with two detectors per structure for a total of four detectors. The total cost incurred per location is $43,450.00.

8. ANNUAL OPERATING AND MAINTENANCE: Not available.

1. TRAFFIC CONTROL: Variable Message Fog Hazard Warning Signs

2. ENVIRONMENTAL CONDITION: Fog

3. IMPLEMENTING STATE: Oregon

4. OPERATING STATUS: Installed November 15, 1968; currently operational.

5. AVERAGE DAILY TRAFFIC: 1968 -18,000 ADT; 1974 - 23,000 ADT.

6. DESCRIPTION: The system consists of six remotely controlled 7' x 32' variable message red neon fog marking signs mounted over the center of the roadway on six miles of Interstate 5 near North Albany. Each sign displays the messages "Wreck," "Fog," "Slow" and "Speed" with 10 mph increments from 10 to 50 mph. Traffic control procedures are initiated on the basis of the State Police Patrol officers' judgement. The telementered controlled signs are activated by patrol officers through a radio call to the Albany State Police office. During high density fog conditions, additional support is provided by State Police officers to maintain speed and traffic conditions. A series of induction loop speed detectors were installed to monitor the traffic stream and measure the effect of these warning signs on vehicle operations. The loop detectors are installed at 10 locations, six of which correspond to the sign locations and the other four placed at either end of the stretch to monitor incoming flow. All signs can be operated manually on site with toggle switches in the sign control box. The placement and number of signs were determined based on an extensive analysis of past accidents.

7. INSTALLATION COST:

   Preliminary Design - $4,800
   6 Fog Warning Signs and Installation - $151,000
   Speed Research Loop Detectors - $112,000

8. ANNUAL OPERATING AND MAINTENANCE COST:

   $500/year - Budgeted.

1. TRAFFIC CONTROL: Chain Control

2. ENVIRONMENTAL CONDITION: Snow

3. IMPLEMENTING STATE: California

4. OPERATING STATUS AND YEARS IN OPERATION: Chain control has been utilized in excess of 20 years.

5. AVERAGE DAILY TRAFFIC (ADT) VOLUME: West Slope of Interstate 80 - 16,400 ADT; East Slope of Interstate 80 - 14,900 ADT.

6. DESCRIPTION: The technique provides a control over vehicular movement during snow conditions by requiring either snow tires or chains beyond key locations.

   Chain control is established by field personnel judgment of the severity of the snow conditions, and signs are uncovered or placed in operation accordingly. At each chain control station, flashing lights are displayed to attract motorists' attention. The primary duties of the CHP during the time chain control is in operation include:

   - Enforcement of all traffic laws relative to chain control, road closure and normal vehicle operation.
   - Control of tow truck operations.
   - Provision of adequate patrol to assist and protect the motoring public.
   - Investigation of vehicle collisions.
   - Short-term traffic control at chain control points.
   - Enforcement of chain installer permits.

   If traffic becomes extremely hazardous during the time chain control is in effect, CHP will commence convoying cars over the summit to maintain flow and minimize collisions.

7. INSTALLATION COST:

   . Steel studded tires on front wheels of each patrol car - $65 each.

   . 4-wheel drive vehicle with winch for towing vehicles - $5,000.

   . Pickup trucks - $11,000 each.

   . Changeable message signs - $50,000 each.

8. ANNUAL OPERATING AND MAINTENANCE: No estimates available

1. TRAFFIC CONTROL: Chain Control

2. ENVIRONMENTAL CONDITION: Snow

3. IMPLEMENTING STATE: California (Truckee Area)

4. OPERATING STATUS AND YEARS IN OPERATION: In effect since 1975.

5. AVERAGE DAILY TRAFFIC (ADT) VOLUME: Not available.

6. DESCRIPTION: At the onset of inclement weather conditions, chain control is established by D.O.T. All chain control areas are marked, first by a sign indicating "Chains Required One Mile Ahead" followed by a sign at the perimeter of the affected area indicating that chains are required. On Interstate 80, chain control trucks are stationed by D.O.T. to check all vehicles proceeding into the chain control area. These mobile chain control units are equipped with flashing lights, two-way radio and snow warning signs. The three types of chain control used in the Truckee Area are designated as "R1," "R2" or "R3." These controls reflect the severity of weather conditions as follows:

   - R1 Control: The purpose of this control is to alert the public of impending weather conditions. This control allows passenger vehicles and trucks which have an unloaded weight of 6000 pounds or less to pass through the chain control area without chains, provided they are equipped with snow tires in good condition. Chains are required on other vehicles and trucks.

   - R2 Control: This allows passenger vehicles and trucks which have an unloaded weight of 6000 pounds or less to proceed into the chain control area only if they have chains on the rear wheels. Vehicles weighing 6500 pounds or less, with snow tires on all wheels, however are allowed to proceed into the chain control area. This control is established when traffic volume is such that any congestion in traffic flow would affect a significant number of highway users.

. R3 Control: At this level of control, chains are required on all vehicles with no exceptions. This control is established when adverse conditions prevail to the extent that the safety of the motorist is in jeopardy. All vehicles entering the chain control area are required to carry chains.

When chain control is established, all the "R" signs are turned by CHP personnel, upon the request of the D.O.T. road foreman. The chain control trucks are manned by D.O.T. flagmen, who are responsible for promptly reporting vehicles running the control to aid the CHP with their enforcement efforts. Tow truck rotation lists are maintained by the CHP. The responsibilities of CHP include enforcement of traffic laws, protection of the public, investigation of accidents and removal of abandoned vehicles. When the traffic is heavy enough to warrant CHP assistance at the chain control truck, an officer will be assigned to aid the flagman in moving traffic through the chain control area as rapidly as possible. At all chain control areas, permits are issued to chain installers by Cal-Trans. A road closure is enforced by CHP upon request of D.O.T. personnel. Officers participating in this program, receive training on special aspects of driving in chain control areas.

7. INSTALLATION COST: Not available.

8. ANNUAL OPERATING AND MAINTENANCE: Not available.

1. TRAFFIC CONTROL: Round Robin and Vehicle Escort (No chain control).

2. ENVIRONMENTAL CONDITIONS: Snow

3. IMPLEMENTING STATE: California

4. OPERATING STATUS AND YEARS IN OPERATION: 4 years.

5. AVERAGE DAILY TRAFFIC (ADT) VOLUME: 1974 - 28,000; 1973 - 22,500.

6. DESCRIPTION: There are three control levels involved in the implementation of the procedure. The type of traffic control in effect will depend upon the intensity and duration of a storm. At the first sign of snow, studded tires are installed and the round robin procedure is initiated. This procedure establishes traffic control by substantially reducing the speed of following vehicles. Round Robin will continue through the affected area until the condition eases or more stringent control becomes necessary. Level two and three are considered emergency operations.

   . Level Two - Escort Service

   When vehicles begin to slide and spin out due to loss of traction on snow, available patrol units will provide escort through the affected area. This operation will be in conjunction with the snow removal and sanding equipment of Cal-Trans. If adverse conditions prevail, a suitable location for the temporary halting of all traffic outside the affected area will be determined and patrol units will be assigned to stop all traffic at selected locations. Cal-Trans personnel will assist at such locations as quickly as they can arrive.

   . Level Three - Highway Closure

   When the intensity of a storm is such that Cal-Trans equipment is ineffective in clearing the roadway sufficiently to allow escorts, complete closure will be necessary.

A patrol unit will be assigned to each location to assist and provide enforcement action as required.

7. INSTALLATION COST: Changeable Message Sign - $50,000 installed. CHP installs (2) studded tires each unit - $65 each.

8. ANNUAL OPERATING AND MAINTENANCE: No data available.

1. TRAFFIC CONTROL: Pilot Reporting System

2. ENVIRONMENTAL CONDITION: Snow or ice

3. IMPLEMENTING STATE: Michigan

4. AVERAGE DAILY TRAFFIC (ADT) VOLUME: Not Identified.

5. DESCRIPTION: The intent of this system is to keep the public informed of all hazardous driving conditions. Agencies responsible for the maintenance of road systems, report hazardous conditions to the designated State Police Post who will immediately notify the State Police Operations and Communications in Lansing. These road condition reports are made in accordance with the following three conditions:

"Condition Yellow"
"Condition Red Alert"
"Condition Red"

The information is compiled by the operations and Communications Division and released to all news media on a 24-hour basis. All news releases provide information on road conditions as specified under the "Condition" reported by the agencies.

A "Condition Yellow" is used when roads are covered with snow or ice and traffic is moving at a slow pace. The motorists are advised to drive carefully. A "Condition Red Alert" is used when storm conditions become extremely hazardous with heavy snow and severe impeding removal operations to the extent that only one lane can be maintained open to move traffic. Upon receipt of the message, Highway Representative will alert and coordinate with affected District(s) maintenance engineer for assessment of road conditions, equipment available within District and selection of road closure terminals. Road conditions are released to all news media to warn the public. A "Condition Red" is a request for road closure when the agency is unable to maintain at least one open lane for travel. When State Police Operations report a "Condition Red" to a Highway Executive Staff, decisions regarding the closure of road(s) will be made. Upon decision for road closure, emergency procedures will be implemented. These procedures include:

- Recommendations of alternate routes
- Provision of information on road closures
- Provision of necessary traffic controls such as signs, signals and barricades at all terminal points.

Assistance will be provided in the removal of abandoned vehicles within areas of closures. When weather condition eases, condition will revert to "Condition Yellow".

6. No cost estimates available.

1. TRAFFIC CONTROL: Dust Warning System

2. ENVIRONMENTAL CONDITION: Dust

3. IMPLEMENTING STATE: Arizona

4. OPERATING STATUS AND YEARS IN OPERATION: Developed in 1973.

5. AVERAGE DAILY TRAFFIC (ADT) VOLUME: Not available.

6. DESCRIPTION: The Dust Warning System consists of a series of 40 changeable message signs and warning lights which provide information on dust storm warnings. The system includes a public educating effort using the news media, travel clubs, special brochures and informational displays at rest areas along the highways. These brochures and informational displays are designed to aid the motorist in taking precautions when travelling under adverse conditions.

   The warning system includes the following procedures:

   1. The National Weather Service office or patrolmen in the area provide notification of impending or existing storms.

   2. An alert message is provided by the NWS to all radio stations in Arizona.

   3. The changeable message signs in the area of the storm are activated centrally from Phoenix. Patrol units are placed in those areas to control the traffic and provide escort service through the area of reduced visibility. These signs are spaced approximately five miles apart in both directions over an 80 mile stretch of interstate highway. The National Weather Service and Department of Public Safety patrolmen in the area of storm, provide advance information to the sign systems "control console" located at DPS communications in Phoenix. The DPS dispatcher has a control console and Status map for the entire system. Each sign displays an identifying number on a delineator plate mounted on the support. Corresponding numbers identify each sign on the map display of the control console in Phoenix.

The three sign modes incorporated in the system are given below:

Mode 1 - Normal
Mode 2 - Early Warning "Gusty winds use caution"
Mode 3 - Severe Warning "Blowing dust reduce speed"

Upon receipt of a storm warning, the dispatcher will first place all signs in Mode 2. When conditions of poor visibility are encountered (less than 1/4 mile), the officer in the field will request the dispatcher to place all signs within 10 miles of his location in Mode 3. The signs are changed remotely by the Phoenix dispatcher to the proper message mode. These sign changes will be indicated by a flashing red light on Status Map. If a motorist encounters a sign in the warning mode, he can leave the freeway and seek shelter on the crossroad. When weather conditions change, appropriate messages are displayed by the dispatcher. In the event of communications failure, the signs are operated manually by a maintenance man or a patrol officer.

7. INSTALLATION COST: $737,733.

8. ANNUAL OPERATING AND MAINTENANCE: $33,000/year.

1. TRAFFIC CONTROL: Round Robin Convoying of Vehicles (Operation Dustbound)

2. ENVIRONMENTAL CONDITION: Dust

3. IMPLEMENTING STATE: California

4. OPERATING STATUS AND YEARS IN OPERATION: Developed in 1973.

5. AVERAGE DAILY TRAFFIC (ADT) VOLUME: Interstate 5-8000/9000 (1975)

6. DESCRIPTION: The following procedures are employed during Operation Dustbound.

   The Weather Service provides the area dispatcher with information on weather conditions. When adverse conditions prevail, the field operations officer and the State Division of Highways Maintenance Foreman are notified by the CHP dispatcher, and traffic control measures are initiated. Upon receipt of notification of the possibility of strong winds, available additional personnel are scheduled to those beats by the scheduling sergeant. A priority response schedule for other units developing emergency situation will be designed by the shift supervisor. The shift supervisor is also responsible for the coordination of all patrol unit operations.

   Depending upon the visibility factor, patrol units on either side of a severe dust area slow or stop all traffic from entering a zero visibility (200 feet or less) area by use of warning lights, warning signs, emergency road flares and other available aids. Escorts or Round Robin procedures are employed to avoid delay, and allow traffic to continue without causing any inconvenience. When roads have to be closed, Division of Highways personnel are notified and requested to place appropriate barricades and signs informing the public of the closure and alternate route for use. SIGALERT procedures will be implemented to inform the public of weather conditions.

7. INSTALLATION COST: Dust Masks - $7.00 each; Goggles - $1.75 each.

8. ANNUAL OPERATING AND MAINTENANCE: None except replacement of dust masks and goggles.

1. TRAFFIC CONTROL: Warning/Route Diversion Signs

2. ENVIRONMENTAL CONDITION: Sandstorm

3. IMPLEMENTING STATE: California

4. OPERATING STATUS AND YEARS IN OPERATION: Signs installed for one and one-half years.

5. AVERAGE DAILY TRAFFIC (ADT) VOLUME: Not available.

6. DESCRIPTION: Signs that display warnings such as "High Winds Ahead," "Sandstorm Ahead," etc., are installed on the perimeter of areas with recurring sandstorm problems. SIGALERT public broadcast messages are initiated and wind/sand signs are opened during sandstorms by Patrol personnel. Pilot lights for each location have been installed to indicate the status of signs. Alternate routes are recommended when adverse conditions prevail. A taped road and weather conditions bulletin is maintained to reduce the workload on dispatchers during adverse weather conditions. When severe local weather conditions such as cyclones occur, the U.S. Weather Bureau is notified.

7. INSTALLATION COST: Not available.

8. ANNUAL OPERATING AND MAINTENANCE: Not available.

1. TRAFFIC CONTROL: Crosswinds Signs and Wind Socks

2. ENVIRONMENTAL CONDITION: Crosswinds

3. IMPLEMENTING STATE: New Mexico

4. OPERATING STATUS AND YEARS IN OPERATION: Not available.

5. AVERAGE DAILY TRAFFIC (ADT) VOLUME: Not available.

6. DESCRIPTION: The system consists of 25 dangerous crosswinds signs and additional crosswinds signs complete with wind socks installed on the highway system. These signs are installed in those locations where crosswinds have potential adverse effect on traffic. Wind socks are installed accompanying these signs on heavily traveled highways.

7. INSTALLATION COST: $60.00 for the dangerous crosswinds signs and $150.00 when they are accompanied by a wind sock.

8. ANNUAL OPERATING AND MAINTENANCE: No estimates available.

1. TRAFFIC CONTROL: Variable Message Sign System

2. ENVIRONMENTAL CONDITION: Flooded underpass

3. IMPLEMENTING STATE: Texas

4. OPERATING STATUS AND YEARS IN OPERATION: Not installed, expect completion by early summer, 1977.

5. AVERAGE DAILY TRAFFIC (ADT) VOLUME: Not available.

6. DESCRIPTION OF CONTROL MEASURE: Variable message signs with flood level sensors display one of the following three messages:

"RIGHT LANE - FLOODED WHEN FLASHING"
"LEFT LANE - FLOODED WHEN FLASHING"
"DO NOT ENTER - UNDERPASS FLOODED"

These signs can be manually, automatically or remotely operated. Sensors are lead to pumps to clear water and the message changes as water level rises.

7. INSTALLATION COST: Capital Cost = $5,500.

8. ANNUAL OPERATING AND MAINTENANCE: No operational data but expect to reduce crew by 75 to 1 during flooding condition.

1. TRAFFIC CONTROL: Changeable Message Signs and Ice Detectors

2. ENVIRONMENTAL CONDITIONS: Snow, ice, fog, bridge icing and flood.

3. IMPLEMENTING STATE: Kentucky

4. OPERATING STATUS AND YEARS IN OPERATION: Not available.

5. AVERAGE DAILY TRAFFIC (ADT) VOLUME: Not available.

6. DESCRIPTION: The traffic control procedures implemented in this State include:

   . Installation of ice detectors and fixed signs

   . Activation of changeable message signs

   . Notification of adverse weather conditions.

   The agencies use detector activated messages, remote activated changeable lights and roadside transmitters to notify the public of hazardous weather conditions.

7. INSTALLATION COST: No estimates available.

8. ANNUAL OPERATING AND MAINTENANCE: No estimates available.

1. TRAFFIC CONTROL: Safety Warning System

2. ENVIRONMENTAL CONDITIONS: Snow, ice or fog

3. IMPLEMENTING STATE: Texas

4. OPERATING STATUS AND YEARS IN OPERATION: 4 years.

5. AVERAGE DAILY TRAFFIC (ADT) VOLUME: Gulf Freeway: ADT in the bound direction before the system operational = 69,600; ADT after the system became operational = 69,200.

6. DESCRIPTION: The purpose of the system is to alert the public approaching crest-type vertical curves of stoppage waves downstream of the crest so that they might gradually reduce the speed and avoid collisions. The system consists of two alternately flashing beacons and a static sign displaying the message "CAUTION - SLOW TRAFFIC WHEN FLASHING". These warning signs are controlled automatically by a digital computer.

7. INSTALLATION COST: $40,100.

8. ANNUAL OPERATION AND MAINTENANCE: $2,000.

1. TRAFFIC CONTROL: Changeable Message Sign System

2. ENVIRONMENTAL CONDITIONS: Snow, Ice or fog

3. IMPLEMENTING STATE: Texas

4. OPERATING STATUS AND YEARS IN OPERATION: Has been effective since 1973.

5. AVERAGE DAILY TRAFFIC (ADT) VOLUME : Gulf Freeway, not identified.

6. DESCRIPTION: The primary objective of the system is to provide motorists with adequate information on freeway conditions and alternate routes and thus reduce traffic volumes and congestion, especially during lane closure conditions. Three changeable message signs were installed to improve traffic operations and evaluate sign design and communication techniques. These signs display descriptive freeway condition messages and motorist guidance messages.

7. INSTALLATION COST: $80,000 for three signs.

8. ANNUAL OPERATING AND MAINTENANCE: $29,906 - 1974.

1. TRAFFIC CONTROL: Variable Message Warning Signs, Linear Radio Weather Advisory Remote Weather Detection System.

2. ENVIRONMENTAL CONDITIONS: Snow - Wind

3. IMPLEMENTING STATE: Wyoming

4. OPERATING STATUS AND YEARS IN OPERATION:

   Variable Message Warning Signs installed February 1976. Adverse weather advisory system not yet operational -- planned for next year.

5. AVERAGE DAILY TRAFFIC: (ADT) VOLUME: I-80 Laramie to Rawlins - 4,300.

6. DESCRIPTION: The traffic control techniques that are currently operational in this state include early adverse weather detection and installation of variable message warning signs. Early adverse weather warning is provided through the use of two remotely operated weather detection stations located at Elk Mountain and Arlington. The information on existing and impending weather conditions, is relayed to the district office in Laramie, by these weather detector stations. Each weather station is equipped with a specially designed particle counter which measures the prevailing visual range conditions. These counters are located approximately 1000' to 3000' from the roadway and are elevated about 3 feet off the ground to simulate the motorists line of sight. Snow particles passing through the detector generate signal data which is converted into a visibility measure by a small computer and relayed with wind information to a data platter in the Laramie control room. The data is monitored by the Laramie dispatcher. When adverse weather conditions are anticipated, traffic control measures are initiated upon request of the maintenance supervisor or the District Engineer. Messages regarding speed reduction and adverse weather advisories are posted on two remotely operated variable message signs at either end of the stretch. The patrolmen in the area will assist road crews in changing speed signs, confirming the message display and setting up barricades. Complete road closures are determined by the supervisor or district engineer, based upon reports provided by the

maintenance crew. In the event of a road closure, barricades are established at the major interchanges beyond the VMS. Flagmen are placed at each barricade to provide motorists with information on alternate routes. Stranded vehicles are assisted by towing services coordinated by the Patrol.

7. INSTALLATION COST:

. Variable Message Signs (reflecting type)

- Equipment (2 signs and computer) - $190,000
- Installation - $30,000

. Weather Detection System

- Total Cost = $20,000 (each station)

. Linear radio advisory system

- Total Cost = $125,000.

8. ANNUAL OPERATING AND MAINTENANCE:

. Variable Message Signs

- $500/month lease of dedicated telephone lines
- $350/character replacement cost
- $27/month data conversion set

. Weather Detection System

- $200/month lease telephone charges

. Linear Radio Advisory System

- $500/month telephone line charge.

APPENDIX B

ANNOTATED BIBLIOGRAPHY

I. CONDITIONS

Articles

1. Debris and Hazardous Materials

Bauman, Paul. "Evolution of Debris Control Methods." Southwest Builder and Contractor, V. 132, No. 24, December 12, 1958, pp. 68-75, 72.

Los Angeles county flood control district.

Byrd, William K. "Transportation of Hazardous Materials." Public Safety, 1975, pp. 29-35.

Federal Highway Administration, U.S. "Helicopters to Patrol Freeways Seeking Accident-Causing Debris." Department of Transportation News, FHWA-334, July 2, 1969, pp. 1-2.

Helicopters, television cameras and two-way radio communications will be employed in a new highway safety project aimed at keeping the freeways of Los Angeles, California, free from accident-causing wreckage and hazardous debris. Helicopter crews will maintain surveillance of the freeways, dispatching special emergency patrol equipment to clear the highways of accidents, disabled vehicles, truck spillage and other debris that pose dangers and impede traffic flow. Specialized vehicles will be developed to achieve quick and effective hazard removal. A new California Highway Patrol Academy will be constructed to provide training of local police officers as well as patrol recruits. When expansion of the academy is completed, in-service training will be available for every highway patrolman every two years. It will enable the academy to provide training for local traffic enforcement police also. The expansion of the academy is greatly needed to handle the growth in traffic enforcement personnel throughout the state.

"New Project Aimed at Keeping Road Cleared of Debris." Transport Topics, No. 1775, July 14, 1969, p. 15.

Helicopters, television cameras, and two-way radio communications will be employed in a special new highway safety project aimed at keeping the freeways here free of accident-causing wreckage and hazardous debris.

2. Dust

"California Research Team to Study Freak Dust Storms." American Highways, V. 51, No. 4, October 1972, p. 15.

A special research team assigned to determine methods of neutralizing calamitous effects upon traffic of freak dust storms.

Eaves, Royce, C. "Dust Control." Military Engineer, V. 65, No. 423, January-February, 1973, pp. 36-37.

Tests covered over 355 materials evaluated in the laboratory for penetration, curing, resistance to wind and rain erosion, and exposure to sunlight on five soil surface conditions with three distinctly different soil types: sand, silt, and heavy clay.

Ireland, E.F. "Dust -- Driving Problems -- AHD's Answer." Arizona Conference Roads and Streets Proc., April 1972, pp. 45-55.

In an effort to alert motorists to the potential hazards of dust storms, a number of steps have been tried over the years in the State of Arizona. This report describes several of these steps, including a current project to provide a warning system capable of being automatically activated from visibility detectors. In summary, it was pointed out that the Arizona Highway Department has adopted a multi-disciplinary approach to this problem, feeling that early detection and alerting are only as good as the general public has been disciplined to utilize this information. With

the cooperation and the facilities of the radio and TV broadcasters, the petroleum industry and others interested in safe highway travel, the Arizona Highway Department is conveying this information to the motorist so that when he does see the signs "reduce speed-blowing dust," backed up with high intensity strobe lights, he will have some idea of what he should do.

"Motorist Warning System Under Test by Arizona Highway Department." Highway Research News, No. 45, Autumn 1971, pp. 36-39.

Prototype signal features an anemometer that is pre-programmed to activate strobe lights when wind conditions are sufficient to create dust storms in the area. These amber-colored flashing lights will draw motorists' attention to dust storm warning signs on which the signals are mounted.

"Warning Signs Flip for Safety When Storms Lash Roadway." Rural and Urban Roads, V. 15, No. 11, November 1972, p. 44.

Changeable-message signs are described which are used on sections of highway frequently subjected to high winds and dust storms. The signs are spaced at 5-mile intervals along an 81-mile stretch. The three messages offered are worked by a dispatcher who obtains weather information from the national service, police patrols and volunteers. The tubular steel anchored in 3-ft. diameter reinforced concrete bases 12 ft. deep.

3. Floods

General

Andrews, W. J. "Indiana Flood Control Projects and their Influence on County Highway Planning." In Road School, Purdue University, Lafayette, Indiana, Proceedings, 1962, pp. 219-234.

Indiana's flood control and water resources program is making significant progress and in so doing, involves in a direct way the road network of the State. At the same time, the highway programs, particularly the

interstate and primary state road systems, exert a powerful influence upon the water programs.

Crook, Leonard T. "Lessons Learned From Developing Specific Programs for Flood Control." In International Conference on Water for Peace, Washington, D.C., V. 7, 1967, Water For Peace, pp. 835-846.

Programs developed in the United States to optimize flood plain use, the relation of legal authorities and institutional objectives to the types of programs evolved, and the influence of social objectives and economic conditions on those programs are described. A philosophical foundation is laid for discussion of the proper spheres of activity for the various levels of private and public agencies. The nature, source, and character of floods, flood problems, and the types of solutions feasible for various situations are evaluated. The degree of reliability and the probable future effectiveness of weather forecasting and weather modification are projected. Experience with flood warning is discussed.

Farin, S. E. "Flood Damage and Associated Highway Problems." In Arizona Conference on Roads and Streets, University of Arizona, Tucson, Proceedings, 1965, pp. 23-26.

Discusses floods in California - concludes that without careful evaluation of the situation, efforts to save relatively small amounts of highway construction funds by such things as raising bridge footings, being skimpy on waterway clearances, introducing reducers for the purpose of decreasing pipe size at points of increase in gradient, and failure to provide appropriate erosion protections at obvious points of potential scour, may, in the long run, prove to be poor economy.

"Flooding: If You Can't Avoid It - Minimize It!" Better Roads, V. 43, No. 12, December 1973, pp. 18-25.

Dallas has a plan that mobilizes its highway forces to handle traffic safety in areas that are going to flood when weather conditions are just right.

Hobbs, William H. "Effect of Floods on Transportation." American Society of Civil Engineers, Proceedings, V. 81, paper no. 387, November, 1955, 8 p.

Effects of floods on transportation are examined and evaluated as regards railroads, highways, pipelines, air fields and navigable streams.

Hoyt, W. G., and Langbeim, Walter B. "Protection Through the Control of Water; Floods and the Constitution; Our Present Flood Control Policy." In Their Floods, 1955, pp. 138-186.

The volume presents some facts and fundamentals for the increasing number who are directly concerned with flood problems. Chapter 6 - Protection through the control of water - Flood protection has as its purpose and function the full-time occupancy of lands and structures that would otherwise be subject to damage by flood waters either through inundation or through the dynamic force of the flood. Chapter 7 presents constitutional cases related to floods. Chapter 8 presents federal flood control policy.

"Role of Road Departments in Flood Emergency." Better Roads, V. 26, No. 1, January 1956, pp. 21-22, 46+, Editorial p. 4.

States in northeast suffered damage estimated at nearly $1 billion in floods that struck last August and October. Road officials credit team spirit and willingness of personnel to work long hours for organizational efficiency in face of emergency.

Teipel, John. "High Water Response Plan for Flood Control." Public Works, V. 155, No. 7, July 1969, pp. 82-83.

High water response plan developed in Dallas, similar to response plans used for alerting crews handling snow and ice problems.

U.S. President's Water Resources Policy Commission. "Flood Management." In Its Report, V. 1, Chapt. 15, pp. 141-147.

Discusses need to reexamine our whole theory of flood control, to improve its effeciveness and to make sure that the large sums being appropriated are spent wisely. Offers recommendations on the basis of its review of the place of flood control in comprehensive river basin programs. Also briefly discusses flood forecasting.

Detectors and Sensors

"Flood Forecasting." Public Works, V. 95, No. 9, September 1959, pp. 113-115.

Radio network forms backbone of a complex communication system used for flood forecasting in Pennsylvania.

"How to Predict Floods." Newsweek, V. 79, No. 26, June 26, 1972, p. 78.

National Weather Service (NWS) has long been working on the problem of how to predict flash floods, now the prospects are that a wide-ranging early-warning system may be in operation fairly soon.

NOAA (U.S. Nat'l Oceanic and Atmospheric Administration). "... New Radar Techniques...." Improve Warning of the Flood... V. 2, No. 3, July 1972, p. 8.

Max Kohler, National Weather Service Associate Director for Hydrology, says new radar techniques and automatic sensors will vastly improve warning of the flood that strikes in a flash.

"New England Flood Warning Service." State Government, V. 29, No. 4, April 1956, p. 58.

"New Forecasts Help to Meet Flood Threats." American City, V. 77, No. 12, December 1962, p. 155.

New forecasts help to meet flood threats (Chicago area - municipalities).

Yevjevich, Vujica. "Systematization of Flood Control Measures." American Society of Civil Engineers, Proceedings, Journal of the Hydraulics Division, V. 155, No. Hy 11, November 1974, pp. 1537-1548.

A general review is given of trends in flood control, as seen by the author. Five significant areas in systematization of flood control measures are: prevention; prediction; flood-plain proofing; physical measures of flood control (divided into extensive and intensive); and flood insurance.

4. Fog and Visibility

General

"A Fog Broom Has Been Tested By the New Jersey Highway Department with Promising Results." Civil Engineering, V. 36, No. 8, August 1966, p. 23.

Blackwell, H. Richard. "Roadway Illumination and Visibility in Fog." Illuminating Engineering Society Journal, V. 1, No. 1, October 1971, p. 59.

Program of studies of roadway illumination and visibility in fog, using model-scale simulation with man-made water droplet fog.

"Breaking the Fog Barrier." Traffic Safety, V. 51, No. 4, October 1957, pp. 18-19.

In demonstration at Pennsylvania State University, scientists proved that driver can see in fog with right kind of lighting.

"California to Test Charged Spray Said To Cut Fog." Automative News, V. 47, No. 4375, March 6, 1972, p. 21.

A fog-hole cutter developed to assure improved visibility for truck and automobile drivers developed by California Division of Highways.

"Driving in Fog." Illinois Highway Bulletin, V. 37, Nos. 3-4, March-April 1971, p. 2.

Some findings of the researchers which may help avoid collisions.

"Fog a-go-go." DRPA Log (Del. River Port Authority), V. 1, No. 3, March 1966, p. 19.

A highway dept. experiment enables New Jersey to sweep roads clean with unique "fog brooms."

"Fog Dispersal." Air Transport World. V. 5, No. 6, June 1968, p. 11.

From one to four U.S. airports will make operational use of new warm fog dispersion chemicals and techniques similar to those which last spring had a 75% success rate in tests at Sacramento, Calif.

"Fog, Superhighways." U.S. News & World Report, V. 75, No. 25, November 12, 1973, p. 77.

If you should get trapped in fog on a freeway or any other road, the Nat'l Safety Council suggests ways to reduce your risk.

"Fog Surrounding the Fog Problem Being Swept Away by New Jersey's Unique Nylon Broom." Highway Research News, No. 23, May 1966, p. 5.

Device changes floating fog to running water.

"Highway Fog Horn Tried on Jersey Turnpike." Traffic Engineering, V. 28, No. 2, November 1957, pp. 51-52.

Highway fog horn - to supplement existing signs which warn of fog ahead and caution motorists to drive slowly.

Kocivar, Ben. "How Science Wages the Fight Against Fog." Popular Science, V. 252, No. 2, February 1973, pp. 76-78, 152.

New techniques can clear airports for safer landings, and some day may make highway driving easier.

"Lasers: Seeing Through Fog." Industrial Research, V. 11, No. 1, January 1969, pp. 17-19.

Myers, Joel, N. "Fog." Scientific American, V. 29, No. 6, December 1968, p. 74.

A kind of ground cloud, fog can halt sea, air, and highway travel. When combined with air pollutants, it can be lethal. Ways are known, however, not only to dissipate fog but also to inhibit its formation.

Bibliography, p. 144.

"New Jersey Tests Fog 'Sweepers'." Better Roads, V. 36, No. 3, March 1966, p. 18.

Engineering adapted "fog trap" used in Chile to collect moisture for irrigation of valleys. Closely spaced nylon monofilament thread placed on simple redwood frames, which were dubbed "fog brooms" because they were expected to sweep moisture from the roads.

"New Project Analyzes Deadly Fog." American City, V. 86, No. 2, February 1971, p. 87.

Office of Research, Reported by Richard N. Schwab. "Minimizing the Hazard of Restricted Visibility in Fog." Public Roads, V. 37, No. 2, September 1972, pp. 53-56.

The purpose of this article is to briefly describe the nature of fog and its formation; effects of fog on driving and accidents; current fog abatement

techniques; and possible guidance systems to aid drivers in minimizing the hazards encountered in fog (references, p.56).

O'Leary, M. D. "Operation Fogbound - Safer Highways in California." V. 43, No. 8, May 1973, p. 16.

Operation fogbound was started by the Calif. Highway Patrol in an attempt to reduce accidents and aid motorists during foggy weather.

Pritchard, Benjamin, S., and Blackwell, H. Richard. "Optical Properties of the Atmosphere and Highway Lighting in Fog." Night Visibility, 1958, Highway Research Board Bulletin 191, 1958, pp. 7-16.

The object of the research to be briefly described in this article was the development of methods for improving visibility on the highway in fog by lighting installations of special design. Basic information about the light-scattering properties of fog has been obtained, the capabilities of various methods of approach to the problems of fog have been evaluated, and methods of simulation have been developed. Simulator tests at Pennsylvania State University and the University of Michigan have confirmed the fact that contrasts of objects on the roadway can be improved if a new concept of street light design, suggested by the scattering data, is adopted.

"Road Research." British Road Federation Monthly Bulletin (Great Britain), No. 281, July 1965, p. 149.

Laboratory's new track designed for research in traffic and safety measures with particular emphasis on vehicle behavior. Track to also provide means for experiments on guidance and control of vehicles in fog.

"Seeing Through Bad Weather." Optical Spectra, V. 3, No. 1, January-February 1969, p. 39.

A gated viewing system that will penetrate 355 ft. of adverse atmospheric conditions in complete darkness or in daylight, described as first device to provide visibility in fog, heavy rain, blizzards and sandstorms.

"Simulates Highway Fog." American City, V. 84, No. 5, May 1969, p. 155.

A large-scale chamber in Ipswich, Mass., can reproduce fog conditions to any specification. Major purpose is to simulate fog conditions on highways to find ways to control it through better lighting methods.

"Special Danger: New Highway Research Board Study Probes Effects of Fog." Transport Topics, No. 1827, August 17, 1975, p. 18.

"Summer Driving Weather." Driver, V. 8, No. 12, May 1975, pp. 25-24.

Coping with fog; rain; hydroplaning; some wet weather tips.

"Sweep Away the Fog." Engineering News Record, V. 176, No. 8, February 24, 1966, p. 9.

New Jersey State Highway Department is experimenting with a "fog broom," a rotating, four panel rack closely strung with heavy nylon thread.

"The French Avoid Motorway Pile-Ups in Fog." New Scientist (Great Britain), V.61, No. 895, March 21, 1974, p. 753.

French authorities are considering a closed circuit radio system designed to avoid multiple crashes on motorways.

Theobold, D. J. "Fog, Drivers Reaction and Accidents in California." ITTE, California Univ., Berkeley Proc., 2nd Ann. Symposium, December 1969, pp. 18-22, 2 fig. 1 Tab.

A four-year study was conducted of fog accidents in California to find possible remedial measures. One observation was that the stopping distance was not

enough to be safe in fog. When driving in fog with a visibility of six or seven hundred feet, all the events and conditions must be appraised, decided, and acted upon in less than eight seconds if the vehicle is moving at 65 MPH. A second or two diversion at the wrong time makes a stopped vehicle or other obstruction unavoidable even with several hundred feet of visibility. Another aspect of accident problems that emerged was that while most of the accidents occurred during the morning peak hours, it was usually in the off-peak direction. One of the most discouraging findings was a realization that under most fog conditions, regardless of the control device exerted, drivers drove faster than was considered a safe speed. The fog study conducted by the California Transportation Agency approached the problem from four aspects: (1) The Roadway, (2) Patrol Activity, (3) Public Information, and (4) Vehicle and Equipment. The roadway study involved variable message speed signs, pavement markers, edge lines and colored lane lines. Of the four treatments, the variable message phase appeared the most productive. The second approach via increased exposure either of parked or of moving units of the California Highway Patrol showed that parked units in advance of the test site did cause a 4-6 MPH reduction in mean speed under certain conditions, but under other variables of daylight and fog intensity, the patrol had no effect. The public information approach did not affect the characteristics of driving in the fog.

"View Through Fog." Prod. Eng. 45(1), 24 (Jan. 13, 1969), p. 5. APCA Abstracts (Air Pollution Control Asociation) V. 14, No. 11, April 1969, p. 5.

Laser gives normal visibility in bad weather.

"Virginia Plans to Reduce Fog Hazard." American Highways, V. 52, No. 2, April 1973, p. 16.

A series of steps to caution and guide Interstate 64 motorists during fog conditions on Afton Mountain, including installation of high-intensity, airport runway lights, outlined by Virginia Dept. of Highways.

Wilson, J. E. "California's Reduced Visibility Study Helps Cut Down Traffic Accidents When Fog Hits Area." Traffic Engineering, Inst. of Traffic Eng., V. 35, No. 11, pp. 12-14, 44.

Various means of giving advance warning to drivers of motor vehicles, and the need for greater alertness and caution in driving during periods of reduced visibility are being studied. The purpose of the study is to find means of preventing the multiple vehicle accidents associated with reduced visibility. All the following conclusions, except the first, are for daylight conditions and low to moderate traffic volumes, 5 to 1555 vehicles per lane per hour. The findings are based on a very limited set of conditions, and generalizations should not be made from the following few, and tentative, findings:

1) No instrument is available to measure the distance a driver can see.

2) The fog by itself causes a small reduction in speeds.

3) At fog visibilities of 255 feet or less, posted speeds reduce vehicle speeds approximately another 5 MPH for both low traffic volumes and moderately high volumes.

4) Regardless of the speed posted and/or the safe speed for the distance visible, evidently the average driver will not drive below 38 to 45 MPH in a free traffic flowing condition and with visibility limited to 155 to 255 feet.

5) Posted speeds cause some better grouping of the speeds about the mean.

6) At low volumes, headways are not affected by fog.

7) At moderately high volumes, fog reduced visibility does decrease the number of vehicles travel at short headways, 1.5 to 2.5 seconds.

8) With posted speed limits and limited visibility, the percentage of the very short tailgating headways are reduced.

"Anti-Fog Device for Vehicles." Automobile News, V. 44, No. 4215, January 6, 1969, p. 12.

Warning device to tell a driver when he is near another car that is hidden in fog.

"ATA Urges Warning System to Cut Fog-Caused Accidents." Transport Topics, No. 1813, May 11, 1975, p. 6.

"Automatic Fog Alert System Protects Busy Highway." Rural and Urban Roads, V. 11, No. 5, May 1973, p. 36.

An infrared based electronic sensing and control system (costing $8,555) is described which involves sensors mounted 15 ft. above ground. These measure backscatter and atmospheric attenuation to sense the reduced visibility. When visibility is reduced to less than 1,555 ft. at one or more sensors, flashing warning signs are turned on at either side of the affected roadway interval. The sensors employ transisitor and integrated circuitry to measure the backscatter and absorption of near infrared light energy. The sensor units are maintained at constant temperature to minimize effects of snow and ice. The system powered at 115 volts can be adapted to use for dust detection or other phenomena that affect driver vision.

"DOT Developing Laser Fog Detector." Traffic Safety, V. 71, No. 4, April 1971, p. 27.

"Fog Flasher Aids Western Highway Users." Fleet Owner, V. 68, No. 4, April 1973, p. 25.

An infrared sensing and control system that detects fog has been set up on a Colorado highway to warn drivers when hazardous conditions have set in.

"Fog on Motorways." Editorial - Roads & Road Construction (Great Britain), V. 48, No. 565, January 1975, p. 1.

Remotely controlled motorway signalling system on M-1 motorway in the West Riding of Yorkshire.

"Fog Warning." Better Roads, V.41, No. 4, April 1971, p. 25.

Kentucky gets a new fog alert system.

"Fog Warning System for Southern Freeway." Shire and Municipal Record (Australia), V. 67, No. 3, June 1974, p. 239.

Motorists will be warned of fog by an electric driver-aid system which is being built into the waterfall-Bulli section of the Southern Freeway.

George, L. E. "Fog Warning Sign System." ITTE, California University, Berkeley, Proc. 2nd Ann. Symposium, December 1969, pp. 23-24.

A six-mile section of interstate 5 in Oregon located in the Willamette River Valley, was found to be extremely susceptible to radiation type fog forming conditions during certain periods of the year. The conditions which bring about radiation fog are discussed. In early 1968, an extremely vicious chain reaction accident precipitated a series of investigations and studies involving operating conditions on this portion of the freeway as well as possible corrective measures. The general accident pattern in six years preceding 1966, at which time a warning sign system was installed, consisted of a total of 13 accidents involving 129 vehicles. Seven fatalities and 73 injuries were sustained. Orange, diamond-shape warning signs with battery-operated flashing lights fixed to the top of the post were installed in 1966. These signs were manually operated by State patrol men. Since manual sign activation was too slow, the use was obtained of a remote telemeter control for six signs from the Albany Office of the State Police. Twenty-four hour radio contact between police mobile units on the freeway and the Albany office is used as an early warning system on which decisions are based to activate the signs if there are indications of a critical fog. A research program is being developed to measure the effect of these signs on the traffic stream operation.

Hahn, Jurgen. "Highway Fog Control." Revue Generale des Routes et Des Aerodromes (France), V. 49, No. 555, January 1975, p. 33.

Lutte contre le brouillard sur route - includes English summary.

"Infrared Device Detects Fog." Public Works, V. 154, No. 4, p.58.

Infrared technology combined with an electronic sensing and control system gives motorists advance warning when fog conditions exist on a stretch of interstate 85 S at Fort Morgan, Colorado. The warning system consists of a network of six sensors spaced along a half-mile section of the highway. Located ten feet above ground level, the sensors employ measurement of backscatter and atmospheric attenuation to sense the reduced visibility condition. As visibility is reduced to less than 1,555 feet at one or more of the sensors, flashing warning signs are activated on either side of the affected area. The sensor units employ transistor and integrated circuitry to measure the backscatter and absorption of near infrared light energy. Infrared emitting diodes are used as the modulating source for both measurements. Sensor units are maintained at a constant temperature to minimize effects of ice and snow on their operation.

"Laser Test Set for Fog Detection." Fleet Owner, December 1974, p. 9.

Fog detection by laser beam is being tested as a research project by the New Jersey Turnpike Authority. Fog is a frequent problem on the heavily traveled road, which crosses low-lying and marshy land. The first piece of laser equipment to be tested, made by International Laser Systems, Inc., Orlando, Florida, is expected to be placed about January 15, along the meadowland route of the Turnpike. The system is also designed to detect snow, smoke, and blowing dust. The laser device would transmit data on visual range by cable to the Turnpike Headquarters, where the motorist could be alerted by the radio-controlled electric weather signs. The road already has changeable electric speed limit signs. Two other companies will each

provide the Turnpike with a system and all three will be evaluated. The laser instrument, called the Model VS-1 visibility sensor, measures the transmission of a laser beam through the atmosphere, using an eye-safe laser and an optical receiver. A built-in telescope on the transmitter allows an installer to sight quickly on the receiver. The receiver can then be quickly aligned by means of an integral strength indicator. The transmitter and receiver each stand 4 ft. high and are sealed against weather, dust, and vandalism. Self-contained heaters keep the windows clear during fog or snow. The laser transmitter emits a beam of light through the space being monitored to a receiver 255 ft. away. The unit being tested by the Turnpike Costs 3,255 dollars.

Michaelis, E. E. "Fog Warning: A Step Towards Automation in Accident Prevention." Roads and Road Construction (Great Britain), V. 49, No. 588, December 1971, pp. 435-431.

Heart of any system designed to tackle the task of fog warning is the transmissometer, which is often referred to as the visibility measuring instrument.

"Oregon Tests Fog Warning System." Better Roads, V. 45, No. 3, March 1975, pp. 22-23.

Oregon tests remote-control signs and fog detection device provide warning system for motorists.

Spear, Ed. "Fog Detectors for Controlling Changeable - Message Signs." Highway Research Board Special Reports, Special Report No. 129, 1971, pp. 25-23, 5 fig., 1 tab., 7 ref.

Three instruments that will continuously and automatically measure visibility, detect fog, or do both are the forward-scatter fumosens, the back-scatter videograph, and the transmissometer skopograph, these instruments are manufactured by impulsphysik, GMBH, Hamburg, West Germany and have recently been introduced into the U.S.A. Table compares the characteristics - visibility range, output signal, power, operating temperature, operating humidity, weight, base, and calibration--for each instrument.

Stockman, Harry E. "Seeing in the Dark is Aim of R-F Holography." Electronics, V. 42, No. 24, November 24, 1969, pp. 115-114.

Systems for real-time viewing through rain, fog, or darkness are possible; need more work on detectors and time constants.

"The French Avoid Motorway Pile-Ups in Fog." New Scientist, IPC Magazines, Limited, London, England, V. 61, No. 895, March 21, 1974, p. 753.

A French closed circuit radio system for avoiding motorway pile-ups in fog is described. Each car is fitted with a shock detector coupled to a radio transmitter, which emits a signal in the event of a major accident. The radio signal from the crashed car is picked up by antennae built into the windscreens of following cars within a radius of 855M. A sound signal warns the following driver of trouble ahead and then transmits a radio signal to cars behind, within a radius of 255M. Further accidents are avoided. The system requires the installation of relays on motorways. The cost of the French system is 25 per car which is much higher than the 2-35 per car calculated by TRRL on a strict cost/benefit analysis, and therefore implementation of the French system is unlikely. Techniques for preventing accidents other than those in fog currently being studied by TRRL are mentioned.

5. General Weather Conditons

Anderson, L. G. "Economics of Extended-Term Weather Forecasting." Monthly Weather Review, V. 151, February 1973, pp. 115-25.

Discussion of the theoretical aspects of the economics of extended-term weather forecasting centers around the optimal way of reacting to this information, formulations of value of such information, and methods of comparing different forecasting systems. The effects of improved forecasting systems on logging road costs in the northwest were chosen for a case study of an industry sensitive to rain. In the cases

presented, it is shown that the firms can benefit from extended-period forecasts.

Kontaratos, Anthony N. "A Systems Analysis of the Problem of Road Casualities in the United States." Accident Analysis and Prevention (Great Britain), V. 6, No. 3-4, December 1974, pp. 223-241.

Road accident data reviewed, an accident causation model is proposed and accident causation factors are described in terms of human vehicular and environmental contributions. A comprehensive program of safety-oriented research is outlined and difficulties in setting research priorities are discussed. References p. 241.

Ricker, Edmund R. "Use of Accident Data to Identify Wet-Pavement Locations in Pennsylvania." In Anti-Skid Program Management and Related Papers, Highway Research Record 376, 1971, pp. 18-25.

Identification of wet-pavement accident locations is one of the specific uses of the accident data bank that has been in operation in Pennsylvania since January 1966.

Rosenfeldda. "How Bad Will the Storm Be?" Better Roads, V. 44 NN, March 1974, pp. 19-21.

Here is a proposed formula that will allow a local road superintendent to estimate in advance what equipment and manpower should be made available during any given 12 hour storm period. This formula can be applied to very small areas, thus defeating the generalized normal weather forecast that does not distinguish one local area from another. The ingredients or variables of this formula are rate of snow fall, total snow fall, wind speed, density and terrain. The formula, when worked out, will give a storm severity index which may be correlated and applied to the needs of each individual district, town, or department.

Taylor, E. "Regional Weather Probabilities." Rural and Urban Roads, V. 5, No. 7, July 1967, pp. 57, 65, 63, 7 Tab.

Snowfall tables of various states and areas in the Western United States are presented. From these tables, it is possible to examine the probabilities of above-normal snowfalls, seasonal snowfalls that exceed the capability of organizations manned and implemented for the average conditions. Indeed, extreme seasonal precipitation that will occur just as sure as the below-normal seasons can be predicted. The snowfall is discussed in regard to airport snow removal specifically. From analysis of these western tables, a chart using observed probabilities factors is presented for certain eastern areas. This chart includes the major eastern cities and lists for each the average annual snowfall, projected one in ten years snowfalls, average liquid annual precipitation, ratio liquid-snow, twenty-four hour maximum snowfall and liquid-snow ratio.

6. Ice and Snow

General

Atyeo, H. F. "Snow Removal and Ice Control Equipment Requirements." American Public Works Association Yearbook, 1966, pp. 185-183.

The efficient removal of a snow or ice driving hazard and the restoration of traffic to normal is dependent upon three major factors - plan, personnel, and equipment.

Ainsley, Wm. G. "Snow Removal and Ice Control". Western Association of State Highway Officials; Proceedings, 1965, pp. 555-556.

This paper deals more with the administrative problems connected with snow removal and ice control rather than with the operational problems. The basic problem is equipping the man and the machine and getting them out when and where they are needed.

Lee, Robert E. "Snow and Ice Control." Massachusetts Department of Public Works, Highway Conference, 1961, pp. 7-17.

Duties assigned to the Snow and Ice Congrol Engineer under the supervision of the Maintenance Engineer of Massachusetts Department of Public Works and their snow and ice control program.

Lennon, Joseph T. "Cost Analysis of Snow and Ice Control Operations." American Public Works Association Yearbook, 1967, pp. 158-171.

Discusses factors in measuring costs and performance of snow and ice removal. Calls for the funding and subsequent expansion of the Research Foundation for a continuing program of research concentrating on snow and ice removal projects emphasizing the scientific approach.

"Let's Be Objective About Snow and Ice Control." American City,
V. 84, No. 15, October 1969, pp. 156-158, 115 +.

Ongoing improvements in snow control program.

"Living Snow Fence Works on Summer Erosion, Too." Rural and Urban Roads, V. 15, No. 7, July 1972, pp. 68-69.

In Iowa, living snow fence of selected shrubs "adjusts" wind currents that cause drifting snow. During summer, same shrubs thwart erosion.

Lockwood, Robert K. "Cut Winter Maintenance Costs with Well-Developed Plan.", Better Roads, V. 38, No. 11, November 1968, pp. 29-35.

Highway forces must be geared to do instant battle with winter forces of nature.

Miller, Hugh. "Snow Fences Lose in Competition with Improved Highway Design." Minnesota Highways, V. 17, No. 1, Winter Quarter, 1968, pp. 8-9.

Engineers putting emphasis on permanent snow barriers through designed and landscaping highways to use natural forces.

"Natural Fences to Fight Drifts." Michigan Roads and Construction, V. 67, No. 25, June 18, 1975. p 5.

"Nearly Free Heat May Prevent Pavement Icing." Engineering News-Record, V. 189, No. 21, November 23, 1972, p. 11.

Heat from deep in the ground may be an economical way to de-ice bridges, intersections, runways and other critical areas.

"Prize Winning Section of I-95 Augusta-Fairfield Successfully Grows Snow Fence After Nine Years." Maine Trail, V. 35, No. 8, November 1975, pp. 19-25.

Evergreen seedlings planted nine years ago when the expressway was opened have now matured sufficiently that individual trees are large enough and dense enough to act as a living snow fence.

Reppel, J. W. and Butler, B. C. "A Study of the Economics of the Bare Roads Policy for Winter Maintenance." Highway Engineering Conference, Ohio State University, Columbus, Proceedings, 1962, pp. 311-325.

The primary purpose of the study was to develop comparisons between winter maintenance cost and the benefits derived from these costs.

"Snow and Ice Control." Rural and Urban Roads, V. 12, No. 6, June 1974, pp. 12-17, 28 +.

Good purchasing and upkeep lift high-country plowing; weather forecasting worth it? A look at costs and benefits; the quality and form of private weather forecasts, by Joel Myers; speed plowing, berms, raised grades: how a prairie country does it; off-season school shapes up men and plow unit; new bigger equipment cuts deep-snow plowing costs; runways kept clear with

fast plows and wind vigilance; salt particle size affects fuel use, by Donald Ireland; citizen cooperation speeds city's small snow fleet.

"Snow and Ice Control." "Rural and Urban Roads, V. 11, No. 6, June 1973, pp. 16-23 25 +.

Two cities in Maine: specific needs dictate snow clearing techniques; Dixie eyes new snow plans in wake of huge road damage; Cover story; temperature sensors, echelon plowing, provide fast and economical snow control; salt and its storage dominate snow conference; big diesel tandems plow and haul on thruway; air defense runways rely on special equipment and deicer; deicing chemicals: red flag for ecology or green for safety? New ideas in deicing techniques; preplanning snow removal; how one city raised efficiency; system plowing and new equipment selection score in football town; central salt depot serves Michigan County; extra "push" with repowering cuts plowing time, upkeep.

"Snow Fence Facts and Figures." Rural Roads, V. 14, No. 3, March 1963, p. 46.

Thousands of miles of snowfence, installed along nation's highways and byways, retard drifting snow and help to keep roads open during blizzards.

"Snow Fences Improve Highway Safety." Public Works, V. 154, No. 8, August 1973, pp. 74-75.

Reviews performance of snowfences that have been engineered to serve specific sites. References, p. 75.

"Snow Notes." Better Roads V. 45, No. 3, March 1975, pp. 26-27.

New Jersey adds new equipment; Nevada motorists depend on road advisory service; getting rid of January-in-June in Josemite National Park; snow-fence experiment in Pennsylvania; chemicals tested in Connecticut; Do Studded tires affect highways? Minnesota Department of Highway Study.

Tabler, Ronald D. "How to Use Snow Fences Effectively." American City, V. 89, No. 2, February 1974, pp. 47-48.

In the high plains of Wyoming, snow fences get a severe test. When placed scientifically, it can keep a roadway clear and eliminate costly plowing. Moreover, it can improve roadway visibility and reduce road ice during a snow storm.

_____."Snow Fences Improve Highway Safety." Public Works, V. 154, No. 8, August, 1973, pp. 74-75.

Reviews performance of snow fences that have been engineered to serve specific sites. Reference. p. 75.

"Tollways Try New Snow Fighting Ideas." Rural and Urban Roads, V. 9, No. 7, July 1971, pp. 44-46.

Some have major research going to handle tremendous snow and ice problems.

Wasserman, S. E. and Monte, D. J. "Relationship Between Snow Accumulation and Snow Intensity as Determined From Visibility." 29th Annual East Snow Conference. Proc., V. 17, February 5, 1972, pp. 47-52.

A procedure is presented for estimating hourly snow accumulation from observations of snow intensity or visibility, with the procedure being tested to La Guardia Field, New York City. The relationship between reported snow intensity and estimated snowfall is shown on independent data to be reliable. Results should aid in forecasting additional snow accumulation and in estimating previous snowfall when this information is not available from direct measurements.

"Winter Maintenance Reference Issue." Better Roads, V. 45, No. 7, July 1975, entire issue.

FHWA answers Better Road's questions on road improvements; Chicago snow fighting techniques; City of Omaha has workable program: comprehensive plan aids snow removal operations; heating cables keep bridge snow-free; Performance is what counts: reducing the cost of winter road maintenance; Integration of city divisions: how Flint, Michigan, handles snow fighting and saves tax dollars; Michigan DOH's ideas for 1975: new chemical will tell where and when to impose road weight limits; Snow plowing Toledo streets: rubber-tipped blades easy on roadways; Tests underway in California: air sampling for proposed highways; winterizing equipment for cold weather operation State's road maintenance department not hindered: off-center raised reflective markers aid snow plowing; Ontario Ministry of Transportation research: snow plowing visibility improved with vanes mounted to plows-cab.

"Winter Preparedness Issue." Constructioneer, July 22, 1974, entire issue.

Snow removal procedures at Erie, Pennsylvania, airport among the nation's best; Superintendents school gives a graduate the answers on winter maintenance; Snow clearing equipment plus forecasts keep Pottsville, Pennsylvania clean; A small town has big ideas on snow removal equipment; Morris County, New Jersey, leaves nothing to chance on snow and ice control; Sixty acres of parking lot kept clean at Livingston Mall; snow removal and ice control - 1973 - 1974 style; Regional technical committee on highway and structural maintenance discusses ice control and effects.

Detectors and Sensors

"Bridge Ice Detector." Highway and Public Works, (Great Britain), V. 36, No. 1697, January 1968, p. 32.

Michigan Department of State Highways evaluating a detection system that anticipates frost and ice formation during presence of high humidity and low bridge deck temperature conditions and automatically warns approaching drivers of icy condition by a lighted warning sign.

Ciemochowski, Michael F. "A Detection System for Frost, Snow and Ice on Bridges and Highways." HRR, No. 298, 1969, pp. 17-24.

Describes a system which detects ice, snow and frost on bridge surface and activates a warning light. A description of the operating principles is provided along with a discussion of the experience to date with a competitive system.

_____."Simple Detector Predicts Formation of Ice on Roads." SAE Journal, V. 76, No. 8, August 1968, p. 65.

Detector predicts formation of ice on roadways and bridge decks under both low and high humidity conditions.

"Electronic Ice Detective." Construction Digest (East), V. 41, No. 25, February 13, 1969, p. 145.

On Interstate 64 just east of Frankfurt, Kentucky, a Kentucky River bridge has an ice detector buried in west bound lane. It senses two conditions -- moisture and low temperature.

"Electric Snow Map Added to Virginia's Arsenal of Snow Fighting Weapons." Better Roads, V. 38, No. 3, March 1968, p. 38.

A flick of a switch shows road conditions throughout the State. Maintenance engineers update map three times a day and as major changes develop.

Glauz, William D. "Watch for Ice on Bridge." MRI Quarterly (Midwest Research Institute), Spring 1972, p. 12.

Prevention, eradication, or effective warning of ice on bridges.

Glauz, William D., and Blackburn, Robert R. "Ice Warning to Cut Bridge Accidents." Better Roads, V. 42, No. 7, July 1972, pp. 14-15.

Bridge icing mechanisms; detection and prediction techniques, field testing.

Hay, J. S., and Young, C. P. "Weather Forecasting for the Prevention of Icy Roads in the United Kingdom." Weather Forecasting for Agriculture and Industry, United Kingdom Conference Paper, 1972, pp. 155-65, 3 fig. 1 Tab. 7 Ref.

The costs of preventing icy roads are outlined: Costs of unnecessary applications of salt to roads, costs of corrosion, costs of delays and costs of accidents. The need for improved weather forecasting techniques to reduce these costs is discussed. Current methods for the provision of warnings of icy roads are reviewed, including meteorological office warnings and ice-warning devices, which, individually, tend to give false alarms. A new warning system for motorways is proposed. The system will combine ice-warning devices with weather forecasting. The meteorological sensors will be integrated by a computer and the data will be sent to the local meteorological forecasting office thus combining weather forecasts with actual data on road conditons.

"Ice Detection System Debuts on Rouge River Bridge." Michigan Contractor and Builder, V. 64, No. 36, December 12, 1975, p. 11.

Describes system using 18 sensors imbedded in a concrete bridge deck to give advance warning of bridge icing.

"Ice Detector Installed on Hazardous Bridge." Arkansas Highways,
V. 14, No. 11, November-December 1968, p. 5.

An electronic detector unit to warn motorists of hazardous icing conditions installed on dual I-35 bridges over Arch Street southwest of Little Rock. The unit is equipped with sensors capable of measuring moisture and temperature, which when conditions are right, causes the bridges to become dangerously icy.

"Ice Detector System Can Protect Bridges and Runways." American City, V. 83, No. 12, December 1968, pp. 76-77.

Ice detection system warns of slippery, icy conditions before they actually occur. System evaluated on I-75, Flint River Bridge.

"Icy Bridges, Hazard." Highway Highlights (Kansas), V. 29, No. 8, November 1968, p. 13.

"Watch for ice on Bridge" warning signs posted at all major bridge locations throughout the State. Bridges are subject to icing before it begins to form on roadways.

"'Ice-Tronics' for Winter Safety." Virginia Highway Bulletin, V. 35, No. 12, December 1969, p. 3.

Electronically controlled ice signals to give winter traveller on Virginia's roads another measure of protection.

"Icy Road Alert." Automotive Industries, V. 128, No. 4, February 15, 1963, p. 49.

"Ice Eye" gives motorists warning of impending road dangers caused by freezing. Equipment has a temperature-sensing probe just below surface of road which, when road falls to freezing point, causes a relay to trip.

Kobett, Donald R., Glauz, William D., and Balmer, Glenn G. "Driver Response to Icy Bridge Warning Sign." Traffic Engineering, V. 42, No. 15, July 1972, pp. 18-23.

A field evaluation was made of driver response to a sign warning of an icy bridge. The study was part of an investigation of detection and warning systems for highway ice and snow, and was conducted in Kansas City, Missouri, during 1975-71 winter season. References, p. 23.

Meucci, P. "On the Motorway in the Snow (in Italian)." Autostrade, italy, V. 13, No. 2, February 1971, pp. 4-11.

Methods used in Italy for providing early warning of snow and icy conditions on motorways are described. Up to the minute weather information is available to the motorist at stations distributed throughout the network. These stations, in addition to making use of normal weather broadcasts and special broadcasts directed at the motorway (from nearby airports for example), also have their own meteorological service from which information is collected every two hours. On critical motorway sections, thermometers installed on viaducts are regularly checked by the road police. It is suggested that measures such as these might advantageously be applied in France, where in December 1975, a long stretch of the A-7 Lyons-Marseille Motorway was completly blocked by snow and snowbound traffic for two days.

Myers, Joel, N., and Myers, Barry Lee. "Rain or Snow It Pays to Know." Public Works, V. 155, No. 1, January 1974, pp. 48-55.

Customized service provided by private forecasters not only gives timely alerts to snow fighting forces but may also avoid needless preparation.

"New Snow Melting System." Concrete Construction, V. 18, No. 4, April 1973, p. 188.

Describes a snow melting system activated by a sensor.

"Sensors Warn of Ice." American Motorist, V. 37, No. 11, March 1969, p. 17.

System installed in 1964 on Flint River Bridge near Flint, Michigan. It included instruments which kept a record of air temperature and humidity readings as monitored by detection system, as well as a record of signal actuation.

Stockley, N. H. "Liverpool's Road Ice Detection System." Roads and Road Construction (Great Britain), V. 47, No. 559, July 1969, p. 257.

Ice warning detection equipment installed at strategic points in city's highway system, to transmit warnings of probable and actual icy road conditions to a central control point.

"VDH Plans Ice Detection for 19 Bridges." Construction, V. 36, No. 26, December 29, 1969, p. 12.

In the installation, temperature and moisture detection devices are embedded in the concrete deck of bridges, and warning signs are erected for approaching motorists.

7. Wind

"Wind Socks Alert Motorists on Interstate 89." New Hampshire Highways, V. 24, No. 2, July 1969, p. 15.

Traffic Division of New Hampshire's Highway Department installs advance warning signs and a pair of wind socks along north and southbound lanes of Interstate 89 in Springfield at two separate hillside locations.

Books, Pamphlets, Documents, Reports, Research Projects

1. Debris and Hazardous Materials

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3. Fog and Visibility

General

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5. Ice and Snow

General

Birnie, C. Jr. Bridge Deck Deicing Study Final Report. The Pennsylvania Transportation Institute, The Pennsylvanis State University, 1974, Sponsored by Pennsylvania Department of Transportation, 97p.

Meteorological and surface temperature data from the test site on I-85 for the winters of 1971-1972 and 1972-1973 is analyzed to determine the periods of preferential icing. The annual accumulative hours of preferential icing is proposed as a method of rating the potential of bridges to freeze before the roadway does. A simulation model which measures the response of the bridge and adjacent road surface temperatures to both real and hypothetical weather conditions is discussed. Methods for using this simulation model for rating bridges and for predicting periods of preferential icing before they occur are set forth: A prototype instrument for direct measurement of preferential icing periods on a bridge deck is described and the results of field tests given.

Biss, David J. Bridge Deck Deicing Study - Phase B. Pennsylvania Transportation and Traffic Safety Center, Report TTSC 7157, FHWA R&D Report #2756, (1971), 113 p.

This report summarizes the experimental work conducted during the winter season 1975-71 at the test site on the eastern bound lane of I-85 where it corsses Bald Eagle Creek in Central County.

The data does not indicate any method for reliably predicting preferential data before it occurs. However, much could probably be done to reduce the bridge icing problem by using conservative countermeasures in conjunction with a prediction system based on area-wide weather forecasts and supplemented with inputs from sensors at the bridge sites.

Forbes, Carl; Stewart, Carl, and Spellman, Don. Snow and Ice Control in California. Sacramento, California Division of Highways, PB 195-953, (1975).

Part I: Present Operations; Part 2: Valley Bridge Deck Icing; Part 3: Deicing Chemicals

Part 1: While much of California is free from snow and ice conditions, there are many areas in the State where significant amounts of snowfall occur and where frost and ice are common during the winter months. Some kind of snow removal operation is performed on about 4655 miles of the State System. Snowfall ranges from a trace up to 755 inches annually.

Part II: Areas where bridge decks may frost once over while adjacent pavement is frost-free presents a special problem in ice control. Some means of preventing this potentially dangerous condition is sought. Ice detector/warning signs systems were installed on one bridge to evaluate motorist reaction to "Icy Bridge" warnings.

Part III: Corrosion of steel and other distress on concrete decks which were salted to control ice and snow prompted a search for "non-corrosive deicing chemicals which would compete in cost and effectiveness with the chloride type deicers currently in use.

Huang, Eugene Y. Background/Resource Paper for the Council on Physical Research: Operational Systems for Snow Removal and Ice Control. Upper Great Lakes University Consortium for Transportation Research, (1973), 34 p. and bibliography.

It is proposed that an organized, systematic study be made of the operational systems for snow removal and ice control on land transportation routes and terminals in the upper Great Lakes Region. The ultimate objective of the study is to develop systems that will provide efficient snow removal and ice control operations in this particular area. Emphasis is to be placed on the unique problems attendant to local situations and procedures, as well as their possible solutions. Considerations will be given to innovations that will improve systems output.

Meyer, W.E., Birnie, C. Jr., and Biss, D. J. BridgeDeck Deicing Study: Summary of Phase A Activities. Pennsylvania Transportation and Traffic Safety Center Report TTSC-7514, FHWA R&D Report #2637, (1975), 91 p.

This report is a summary of the project activities between January 1968 and August 1975. The objectives of the project are to study the problems of preferential icing of bridge decks by a) instrumenting bridge site in order to collect data on the frequency and extent of peferential icing and the meteorogical conditions contributing to it, (b) evaluating current methods of ice-detection and prediction and, (c) evaluating countermeasures for preventing preferential icing. The east bound lane of Interstate 85 of the bridge over Bald Eagle Creek in Centre County Pennsylvania was instrumented to obtain meteorogical data at the site and the temperature gradiants in the bridge deck and the approachway. An ice detector was also installed.

"New Snow Melting System." Concrete Construction, V. 18, No. 4, April 1973, p. 188.

Describes a snow melting system activated by a sensor.

"Sensors Warn of Ice." American Motorist, V. 37, No. 11, March 1969, p. 17.

System installed in 1964 on Flint River Bridge near Flint, Michigan. It included instruments which kept a record of air temperature and humidity readings as monitored by detection system, as well as a record of signal actuation.

Stockley, N. H. "Liverpool's Road Ice Detection System." Roads and Road Construction (Great Britain), V. 47, No. 559, July 1969, p. 257.

Ice warning detection equipment installed at strategic points in city's highway system, to transmit warnings of probable and actual icy road conditions to a central control point.

"VDH Plans Ice Detection for 19 Bridges." Construction, V. 36, No. 26, December 29, 1969, p. 12.

In the installation, temperature and moisture detection devices are embedded in the concrete deck of bridges, and warning signs are erected for approaching motorists.

6. Wind

Mugno, Marjie. "Panhandle Paralyzed When the Blizzard Blew In." Texas Highways, V. 18, No. 4, April 1971, pp. 15-14.

Highway department maintenance forces - aided by engineering personnel - worked around the clock to clear the roads, particularly in the northeastern part of the panhandle.

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GENERAL

Birnie, C.,Jr. Bridge Deck Deicing Study Final Report. The Pennsylvania Transportation Institute, The Pennsylvania State University, August 1974, sponsored by Pennsylvania Dept. of Transportation, 97p.

Meteorological and surface temperature data from the test site on I-85 for the winters of 1971-1972 and 1972-1973 is analyzed to determine the periods of preferential icing. The annual accumulative hours of preferential icing is proposed as a method of rating the potential of bridges to freeze before the roadway does. A simulation model which measures the response of the bridge and adjacent road surface temperature to both real and hypothetical weather conditions is discussed. Methods for using this simulation model for rating bridges and for predicting periods of preferential icing before they occur are set forth: A prototype instrument for direct measurement of preferential icing periods on a bridge deck is described and the results of field tests given.

Biss, David J. Bridge Deck Deicing Study - Phase B. Pa. Transportation and Traffic Safety Center, Report TTSC 7157, FHWA R&D Report #2756 (1971) 113p.

This report summarizes the experimental work conducted during the winter season 1975-71 at the test site on the east bound lane of I-85 where it crosses Bold Eagle Creek in Centre County.

The data does not indicate any method for reliably predicting preferential data before it occurs. However, much could probably be done to reduce the bridge icing problem by using conservative countermeasures in conjunction with a prediction system based on areawide weather forecasts and supplemented with inputs from sensors at the bridge sites.

Forbes, Carl, Stewart, Carl, and Spellman, Don. Snow and Ice Control in California. Sacramento, California Division of Highways, PB 195953 (1975).

Part 1: Present Operations; Part 2: Valley Bridge Deck Icing; Part 3: Deicing Chemicals.

Part 1: While much of California is free from snow and ice conditions, there are many areas in the State where significant amounts of snowfall occur and where frost and ice are common during the winter months. Some kind of snow removal operation is performed on about 4655 miles of the State system. Snowfall ranges from a trace up to 755 inches annually.

Part II: Areas where bridge decks may frost or ice over while adjacent pavement is frost-free presents a special problem in ice control. Some means of preventing this potentially dangerous condition is sought. Ice detector/warning sign systems were installed on one bridge to evaluate motorist reaction to "Icy Bridge" Warnings.

Part III: Corrosion of steel and other distress in concrete decks which were salted to control ice and snow prompted a search for a noncorrosive deicing chemical which would compete in cost and effectiveness with the chloride type deicers currently in use.

Huang, Eugene Y. Background/Resource Paper for the Council on Physical Research: Operational Systems for Snow-Removal and Ice Control. Upper Great Lakes University

Consortium for Transportation Research (1973) 34p. & bibliography.

It is proposed that an organized, systematic study be made of the operational systems for snow removal and ice control on land transportation routes and terminals in the upper Great Lakes Region. The ultimate objective of the study is to develop systems that will provide efficient snow removal and ice control operations in this particular area. Emphasis is to be placed on the unique problems attendant to local situations and procedures, as well as their possible solutions. Consideration will be given to innovations that will improve systems output.

Meyer, W. E., Birnie, C., Jr., and Biss, D. J. Bridge Deck Deicing Study: Summary of Phase A Activities. Pa. Transportation & Traffic Safety Center Report TTSC-7514, FHWA R&D Report #2637 (1975) 91p.

This report is a summary of the project activities between January 1968 and August 1975. The objectives of the project are to study the problems of preferential icing of bridge decks by (a) instrumenting a bridge site in order to collect data on the frequency and extent of preferential icing and the meterological conditions contributing to it, (b) evaluating current methods of ice-detection and prediction and, (c) evaluating countermeasures for preventing preferential icing. The east bound lane of Interstate 85 of the bridge over Bald Eagle Creek in Centre County, Pennsylvania was instrumented to obtain meterological data at the site and the temperature gradients in the bridge deck and the approachway. An ice detector was also installed.

Detectors and Sensors

Birnie, C., Jr. and Meyer, W. F. Prediction of Preferential Icing Conditions on Highway Bridges. HRB Special Report 115, Proceedings of an International Symposium held April 8-15, (1975).

This paper is concerned specifically with the situation in which measures are required in a district only for some bridges and not for other bridges or roads and streets.

Glauz, Wm. D, Blackburn, Robert R., Kobett, Donald R. & Sharp, Michael C. Midwest Research Institute, Kansas City, Mo. An Ice and Snow Detection and Warning System; Feasibility Study. Federal Highway Admin., R&D Report #2897 (1971) 254p.

This report covers a feasibility study of highway detection and warning systems for ice, snow, and frost. Among the activities were a thorough literature review, paper study of detection systems, critical review of current and previous field tests, determination of warning sign effectiveness, field testing of six ice and snow detection systems, field evaluation of motorists' response to a warning sign, development and application of a cost-benefit model and development of specifications for several types of ice and snow detection and warning systems. It is concluded that sufficient data were collected for evaluating motorists' response to a warning sign. However, additional controlled field test and analysis of the six detection systems are needed to provide absolute and comparative performance data.

Highway Research Board. Snow Removal and Ice Control Research. Highway Research Record, Special Report #115 (1975).

Articles on snow removal and ice control.

Inoue, Montoya, Baba, Kozabur, and Takada, Yoshiharu. "Ice Detection, Prediction, and Warning System on Highways." Highway Research Board, Snow Removal and Ice Control Research, Special Report #115, 1975, pp.17-26.

Meteorological phenomena such as rain, snow, ice, fog, and wind occurring on highways present obstacles for road maintenance and driving. In particular, ice film forming on road surfaces, snowfall and snow coverage are directly connected with possible traffic accidents, so that countermeasures against these obstructions are of particular importance. An information system has been developed to detect, predict, and give warning of road icing. Prior to the development of the system, extensive survey and study were carried out. These included a metereological survey of highways throughout Japan; a survey of traffic and snow removal and ice

control; a theoretical analysis of predicting metereological phenomena on highways; the development of metereological instruments, system design and operation of metereological information; and similar considerations.

Stewart, C. F. and Sequeira, A. Bridge Deck Frosting - Valley Environment. Sacramento, Calif. Bridge Dept., FHWA R&D Report #2991 (1971) 42p. and Appendix.

The primary objective of the project was to eliminate the need for salting by providing heat inside an enclosure under the deck. In case that was impractical, a secondary objective of improving warning system was sought.

Transport & Road Research Lab., U.K. Icy Road Warnings. Investigator: Williamson, P. J. Funding Agency - Ministry of Transport, London, U.K. Reporting Date: July 1973; Start Date: 1967.

Devices are being developed to warn highway authorities of the onset of ice-forming conditions. At present, such devices depend on the road temperature and the presence of moisture upon it and automatic telephone apparatus is being developed for use with such detectors. Attempts will be made to render the warning more reliable by modifying the sensing equipment. Further studies will be made of the weather conditions leading to ice formation to assist in developing equipment of greater reliability.

Reports Issued:

Experimental Ice-Warning System, P. J. Williamson, Traffic Engineering and Control, Vol. 5, No. 8, pp.477-9 & 497, 1963.

6. Wind

Nordlin, Eric F. and Bourget, Louis. Wind Screen Subdues Gale Force Winds on a Mountain Bridge. Sacramento, Calif., Materials & Research Dept., Research No. M&R 636357-1 (1969) 26p. Illus.

This is a study to determine the feasibility of employing wind screens as a means of preventing vehicle accidents caused by high velocity crosswinds.

II. TECHNIQUES

Articles

1. Motorist Advisories and Traffic Control

Aiken, W. R. "The Distec System: A Sign of Our Times." Highway Research Board Special Reports, Special Report 129, 1971, pp. 37-45, 3 fig.

The Distec System is a new concept in changeable message displays; it has complete obliteration and is unique in its low cost, low power consumption, extraordinary contrast, and ability to be backlighted. It has unlimited variability. Its maintenance requirements are close to zero. The display is passive and is clearly visible under all lighting conditions from direct sunlight to complete darkness. Symbols appear to be continuous lines. Signs are any size, with no separation between adjacent modules. Characters may cross module boundaries and be any size or shape; graphics may be shown. Writing may be proportional; displays may be black on white or white on black. Sign wiring is simple even for thousands of display elements. Remote control is TTL compatible, ASCII coded, low voltage, and direct or by telephone line or radio link. Operation may be marked tape, cards, message keyboard, magnetic tape, punched tape, teletype, keyboard-TV monitor, computer, or a combination of these. All sign circuits may actually be shorted without danger of fire or other hazard. Signs are testd from -45 to +165 F and zero to saturation humidity. The system may be supplied with modules mounted in a subassembly and prewired and tested to fit within a decorative enclosure made to order or supplied by the purchaser. The Mark II modules are 13 inches square and have 155 display elements each.

"All Seeing Eyes." American Road Builder, V. 47, No. 7, July 1975, p. 26.

TV camera used to monitor traffic flow and road conditions on Delaware Memorial Bridge.

American Bridge, Tunnel, & Turnpike Association. "Emergency Traffic Signal Systems."ABTTA Proceedings, 1965, pp. 48-52.

Discusses operation of an idea that was developed which combines special signal controls with a sign. The signal controls the traffic and the sign tells the reason for the control. When a message has been received requiring a signal operation, it is activiated through someone in the Toll Sergeant's Office who selects the message or condition to be flashed on the signs and the appropriate signal indication.

"Are Traffic Aids Worth Their Cost." Engineering News - Record, V. 185, No. 23, June 6, 1968, p. 34.

A report on traffic control devices on John Lodge Freeway in Detroit concludes that some of the expensive electronic equipment now in use on expressway does not justify its own cost in terms of increasing traffic flow.

"Atomic-Powered Sign Directs Highway Traffic." American City, V. 81, No. 9, September 1966, p. 184.

A self-luminous sign, powered by atomic devices, to direct traffic on Maricopa Freeway in Phoenix, Arizona.

"Audible Highway Signing Is Coming?" Civil Engineering, V. 37, No. 11, November 1967, p. 29.

Bureau of Public Roads says that, on many heavily traveled highways, the driver's ability to acquire messages through his visual senses is being taxed to the limit. If additional information must be given - to warn about leaving the freeway, for instance, if a motel or service station is desired - then audible sign may be the solution. (entire article.)

"Automatic Computerized Control Doubles Traffic Flow on Eisenhower Expressway." Traffic Digest and Review, V. 13, No. 12, December 1965, pp. 8-11.

Nation's first automatic computerized traffic control system, in operation for 6 miles on Eisenhower Expressway near Oak Park, Illinois.

Baker, Robert F. "Highway Communication for Service and Safety - Problem and Its Magnitude." American Highways, V. 46, No. 4, October 1967, pp. 4, 8-9.

Several classes of communication systems to be ready for full-scale field trials within two years: disabled vehicle detection system; merge control systems for high-speed; limited access highways; destination direction system for routing vehicles.

Barney, Alan F. "Communication System Technology and Its Use in Traffic Control Systems." Traffic Engineering, V. 41, No. 11, August 1971, pp. 44-48.

Information and design concepts favorably related to traffic control techniques and principles are singled out and highlighted. These facts, teamed with marketing requirements, provide recommendations for the effective utilization of communications knowledge and techniques in traffic control.

Bourne, K. M. "Illinois Tollway is Easy Street With Total Communications." Communications News, V. 15, No. 1, January 1973, pp. 24-9.

A total communications system provides the Illinois State Toll Highway Authority with coverage over 255 miles of tollway. The system consists of an extensive microwave network, a private telephone system interconnected with bell, two-way base, mobile, and portable radios, packet pagers, telemetering equipment, teleprinters, microfiche terminals, and test equipment, all keyed in to tollway, and other State police and emergency and maintenance vehicles. Airplanes and a jet helicopter complement the system for traffic surveillance, parts relay, manhunts, searches for lost children, and other emergencies. The authority is experimenting with a prototype message changer activated by microwave FSK channel data format from a 99 message storage device.

Brown, Delmar L. "Audio Guidance Systems for Drivers." Institute of Traffic Engineers, Western Section, Proceedings, 1967, pp. 133-145.

Although it has been a common practice throughout the world to supply "driver information" by means of signs and visible signs, the need to supply supplementary information by audible signals is intensified by the pace and complexity of modern traffic. The author concludes that none of the electronic schemes will be sufficiently fail-safe to make them into "driver-less-car" devices, but the highway sound-track scanning system embodied in Scanitran development has the advantages of simplicity, low-cost, and compatibility with existing highway systems which make it practical from the traffic engineer's point of view, and has versatility and useful features which give it the consumer acceptance which is necessary to commercial success.

Burrell, J. "Multiple Route Assignments." International Symposium on Theory of Road Traffic Flow, Proceedings, 1968, pp. 215-219.

This paper discusses a multiple route model in which it is assumed that the person making a trip in a network does not know the actual journey time on each link of the network, but that he associates with each link a supposed time, which is drawn at random from a distribution of times having as its mean the actual link time. The person then finds and uses the route which minimizes the sum of his supposed link times. This proves to be a powerful method of obtaining realistic multiple routes between pairs of modes. The procedure can be used for making assignments in unrestrained situations, or where capacity restraint is required, it is found that convergence of iterations is obtained much more quickly using multiple routes, than using single routes.

Carter, Arthur A., et al. "Highway Traffic Surveillance and Control." IEEE Proceedings, 1968, pp. 566-576.

The Bureau of Public Roads of the U.S. Department of Transportation is conducting a major research program in the fields of highway traffic surveillance and

control. The effort involves in-house, contract, and cooperative Federal-State research. Being given individual as well as integrated systems consideration are urban highway methods, freeways and rural multilane highways, and two-lane rural highways.

"Colorado Builds Talking Highways." IMSA Signal Magazine, March-April 1974, p. 7.

A Colorado traffic control system being installed on sections of Interstates 25, 75 and the Denver-Boulder Turnpike will "talk" to motorists by means of computer-controlled signs.

Dudek, Conrad L., Messer, Carroll J. and Mc Casland, William R. "Developments in Real-time Driver Communication Research." Texas Transportation Researcher, V. 6, No. 4, October 1975, pp. 15-12.

Texas Transportation Institute and Texas Highway Department in cooperation with Federal Highway Administration, conducting a research project entitled "Freeway Control and Information Systems." References, p. 12.

Dunn, Robert E. "Electronic Surveillance, Communications and Operational Controls for Interstate Highway 5-Seattle Freeway." Committee on Electronics, AASHO Proceedings, Seattle, Washington, 1969, pp. 75-85.

This discussion first, briefly will describe the closed circuit television surveillance activities that are currently being performed on the Seattle Freeway. And second, presents other surveillance, communications, and control functions developed at national research projects that are being considered for installation in the local facility.

"Electric Warning Signs." Construction Digest (EAST), October 19, 1972, p. 12.

Describes an electronic warning system being installed on I-75 through Cincinnati to warn motorists of congestion and accidents and suggest alternative routes. Uses television cameras and electronic sensors

installed in the roadway.

"End of the Plain Lane." Humble Way, V. 8, No. 2, Second Quarter 1969, pp. 12-16.

Electronics specialists at General Motors Research Laboratories in Warren, Michigan, have perfected a new highway communications system that takes most of the decision-making out of driving. It is called DAIR, an acronym for Driver Aid, Information, and Routing.

"GM Get Contract for Road-Guide System." Automotive News, V. 42, No. 4134, July 24, 1967, p. 15.

Such a system could enable future motorist to travel to his destination without use of maps or route signs, taking instructions instead from automatic communications equipment inside the car.

Hanysz, Eugene A. "A New Concept In Highway Communications." Public Works, V. 98, No. 5, May 1967, pp. 152-153.

Two-way communications, an ear for talking signs, a panel to show signs that lie ahead and a route finder -- all these may become standard equipment in tomorrow's new automobiles.

_____. "Unified Communication System Promises Safer Driving." SAE Journal, V. 75, No. 5, May 1967, pp. 36-41.

DAIR is a system for giving routing instructions, communicating traffic and road signs, and providing radio link for aid and information. It allows the drive to concentrate more on actual driving and results in safer motoring.

Heathington, K. W. "The Development of a Freeway Driver Information System". Illinois Division of Highways, Bureau of Public Roads, IHR-88, 4522-254.

A freeway driver information system is being developed which will be capable of providing real-time traffic information to freeway users and potential users and set in a format which might be incorporated into the operational structure of the Chicago area expressway surveillance project. The system is to obtain maximum efficiency from the use of existing highway facilities before embarking on the construction of new and costlier ones. A conceptual structure is developed through the use of a descriptive systems model. Some specifications as to the input and output requirements are made. An expanded treatment is made of various system elements and their interrelationships. System capabilities for the short-run aspect are described as well as capabilities to adapt over a long-run or evolutionary process. A literature review, made of existing work related to providing information to drivers, gives treatment to existing information systems that approximate a freeway driver information system. Driver attitudes centered around three major areas: (1) an evaluation of the priorities associated with the provision of a freeway driver information system, (2) an evaluation of potential diversion to alternate route and current diversionary practices, and (3) an evaluation of driver preferences for alternative visual information displays. The attitudes toward priority of providing information relative to limited specified improvements in highway facilities can be used by the decision maker as a basis for establishing allocation of resources to highway facilities. The potential response to diversion and current diversionary behavior can be used to estimate the potential response to a freeway driver information system. The evaluation of the reception, comprehension, and response to visual information displays can be used as inputs to a freeway driver information system. The results of the analysis in these three areas are used to design a freeway driver information system for a specified section of the Eisenhower Expressway in Chicago. The design illustrates the location of detectors, information signs, and displays to be used. Some control logic to be used in operation is developed. A structured questionnaire administered to drivers in the Chicago metropolitan area was used to measure driver attitudes. A sample of 1555 drivers residing in Cook County was chosen for the designed investigation. The subjects used in the survey owned a car, made a regularly scheduled automobile trip to a place of employment, school, etc., and resided in Cook County.

Hoff, G. C. "A Comparison Between Selected Traffic Information Devices." Illinois Division of Highways, IHR-88, 4522-254.

Results are reported of a study that was conducted to determine what traffic information techniques might be used to cause drivers to divert around congested parts of the highway system. The results indicate that drivers prefer visual techniques to vocal techniques. Of the different devices tested, a changeable message matrix sign was the most preferred. However, no conclusive evidence could be found that would indicate that this type of device would cause more drivers to divert around a congested section of highway than the other type of devices tested.

International Bridge, Tunnel, and Turnpike Association. "Detection and Handling of Disabled Vehicles." IBTTA Proceedings, 1965, pp. 45-65.

Five panelists discuss detection and handling of disabled vehicles as a means to improve traffic flow.

La Fond, Charles D. "Telemetry, the Road Map of the Future." Electronic Design, V. 17, No. 12, June 7, 1969, pp. 25-26.

Driver-guidance system, to be tested by U.S. Bureau of Public Roads would give continuous directions by audible and visual signals.

Nance, Robert. "Freeway Advisory: New Signs Tell Santa Monica Freeway Drivers What's Going on Ahead." California Business and Transportation Magazine, V. 1, No. 3, May-June 1973, p. 3.

Describes use of electronic signs on Santa Monica Freeway to advise motorists of alternate routes and reason for delay.

Nutt, Sherel. "Mobile Communications Center." Illinois Highway Bulletin, V. 36, Nos. 11-12, November-December 1975, p. 15.

Recent additions to the Highway Communications Systems are two mobile communication vans.

Pavlinski, Lawrence A. "Public Safety Responsiveness to, and On-Site Management of Highway Incidents." Highway Research Record, 157, 1975, pp. 6-11.

The highway safety standard for debris hazard control and cleanup most recently issued by the U.S. Department of Transportation widens the opportunity to improve many highway safety efforts - especially those in the important areas of public safety responsiveness to, and on-site management of, highway incidents. Reviews the new safety standard and safety standards in general.

"Radio 'Trafficasting' Aids Highway Control." Tele-Tech, V. 12, No. 9, September 1953, p. 66.

Buried cable along 3- to 5-mile zone of highway radiates low-power signal in broadcast band. Motorist receives these traffic announcements on auto radio.

"Sign Sorcery." Construction Digest, (East), V. 42, No. 12, August 14, 1969, p. 58.

A trick used for years by magicians is the principle for a new driving aid highway engineers are developing at Ohio State University. Like a magic show, it is all done with mirrors and creates the illusion of seeing signs floating in the air far above the automobile. Called Head Up Display, it gives the driver a better view of highway information signs by projecting their images through a lens in the dash against the sloping windshield, which reflects the images back to the driver's eye.

Stephen, B. W., Rosen, D. A., Mammano, F. J., and Gibbs, W. L. "Third Generation Destination Signing - An Electronic Route Guidance System." Public Roads, Office of Research and Development, Bureau of Public Roads, V. 35, No. 9, August 1969, pp. 193-255, 212.

In this article, highway routing, or navigational methods and procedures, as they exist today are analyzed; the functions, characteristics, normative operation, and constraints of routing methods are delineated; and several novel techniques for communicating directional information to drivers are examined. References, p. 255, 212.

"Study Evaluates Buried Roadway Antennas for Vehicle Communications." Communication Designers Digest, July-August 1971, pp. 18, 25-26.

Two-wire transmission line makes an effective buried roadway antenna for two-way communications with vehicles travelling in one direction.

Tickner, A. H. and Poulton, E. C. "Remote Monitoring on Motorways Using Closed-Circuit Televesion." Ergonomics, V. 11, No. 5, September 1968, pp. 455-466.

"Traffic Information Network Aids Detroit Motorists." Lab Notes (GM Research Laboratories), May 1969, pp. 4-5.

Detroit-based CB Radio Driver Aid Network.

Wardell, E. J. and Murray, R. J. "Computerized Traffic Signal System Maximizes Roadway Network Capacity and Improves Pedestrian Safety at John F. Kennedy International Airport." Traffic Engineering, Institute of Traffic Engineering, V. 38, No. 12, September 1968, pp. 26-28, 35+.

In September of 1967, the Port of York Authority installed a unique traffic signal system in the central terminal area at John F. Kennedy International Airport. This traffic responsive computerized signal system automatically maximizes traffic capacity on the roadways by matching cycle lengths to the speed, volume and density of traffic using the roadway system. A unique feature included in the signal system is a traffic diversion sign system which automatically reroutes traffic from congested roadways to non-congested roadways and optimizes the capacity of the entire roadway network in the central terminal area.

Woods, Donald L. and Rowan, Neilon R. "Driver Communications." Texas Transportation Researcher, V. 5, No. 1, January 1969, pp. 14-16.

Multi-State pooled funds project; problems of communicating visually; hierarchy of driver control requirements; "view-of-the-road" in communication. References, p. 16.

2. Police and Road Service Patrols

Bassett, James E. "Role of the Police in Highway Safety." Kentucky Highway Conference Proceedings, 1966, pp. 71-74.

In highway transportation, police have direct responsibility for traffic law enforcement, traffic direction, vehicle inspection, motorist services, public information, accident investigation, and traffic records. Auxiliary problems are of major interest to the police as they relate to other aspects of highway safety, for there is practically no state or highway activity that does not to some degree affect the police in the pursuit of their objectives.

McLean, C. "More Than 6,555 'Good Turns' Every Month." Public Works, V. 99, No. 6, June 1968, pp. 135-131, 178 & 185.

After the opening of the Interstate Route 94 in Chicago, the Illinois Division of Highways became aware that the expressways could not provide the designed capacities during peak hours without continuous patrol. The Expressway Emergency Patrol was formed under the direction of the district traffic engineer. The primary duty of this patrol was the detection and relocation of accident or mechanical breakdown vehicle disablements which impeded safe traffic flow. Additional patrol duties include: (1) establishing emergency traffic controls and detours by placing appropriate barricades, signs, and lights, (2) assisting at accident scenes by rendering first aid, calling necessary emergency services and helping to extricate trapped or injured persons, and removing accident debris from the roadway, (3) locating disabled vehicles

and assisting motorists by providing gasoline, tire-changing aid, water, and calling for repair service and lending tools for minor and repairs, (4) reporting traffic movement information to the state communications center for distribution to the news media, (5) reporting damaged or faulty state property, (6) warning pedestrians to keep off the expressway and notifying enforcement authorities when personnel or vehicles do not comply with patrol requests, (7) providing travel information assistance, and (8) assisting at special activities or construction work on the expressway. A thorough training course in patrol procedures and operational techniques has been developed. All patrol drivers are required to complete both the basic and advanced red cross first aid courses. The patrol vehicle is a 1 1/2-ton truck chassis with a specially fabricated body. The body is designed to provide the necessary compartmentation for the equipment carried. All trucks are equipped with pusher-type bumpers and rear pintle hooks. Tow-winches have been installed on 21 of the units. A full complement of warning lights and two rotating beacons are standard provisions. Two-way radio communications are maintained in all units. More than 65 individual pieces of equipment are carried in each truck, such as first aid kit, water dry charge and carbon dioxide fire extinguishers, axe and pry bar, fusees and kerosene bombs, traffic cones and barricades, salt, tire changing equipment, water, gasoline, tool box,shovel and broom, blanket and highway maps. Though over 11,555 accidents are experienced each year on the 125-mile urban expressway system, the annual fatality rate is below the national average for expressway fatalities, attesting the value of this service.

3. Traffic Flows and Delays

Ashworth, R. "Effects of Lane Closure on Traffic Delays." Traffic Engineering & Control, V. 11, No. 8, December 1969, pp. 373-375.

Paper considers closure of one lane of a two lane dual carriageway and seeks to quantify delay for a range of speed distribution curves using computer simulation techniques.

Bauer, Herbert J. "A New Speed Command Sign is Developed." Traffic Engineering and Control (Great Britian), V. 4, No. 5, September 1962, pp. 263-266.

Describes development of a changeable speed command sign tested on a four-mile section of highway near Warren, Michigan.

Herman, Robert, and Rothert, Richard. "Driver Response to Speed Signs." Traffic Engineering and Control, V. 6. No. 3, July 1964, pp. 165-165.

Reports on behavior of motorists passing electronically controlled speed signs at Warren, Michigan.

"Instant Bridge Project Shows What Cooperation Can Achieve." Western Construction, V. 55, No. 2, February 1975, pp. 23-27.

Road washouts are a common occurrence in the West, and while they cause traffic delays for normal private vehicles, their most costly feature is obstruction of commercial transportation.

Moskowitz, K. " California Method of Assigning Diverted Traffic to Proposed Freeways." Highway Research Board Bulletin 56, No. 135, pp. 1-26, 14 fig., 7 tab, 3 ref.

California has developed a set of curves showing percent of freeway usage as a function of both time and distance differentials. The primary features of this chart are that it shows: (1) as long as some time is saved, there will be some users of the freeway route no matter how far out of direction they must go, (2) as long as some distance is lost, there will be some 'non-users', no matter how much time is saved, (3) in between there is a gray area where people do not know how much time or distance is saved or lost, or whether it is saved or lost. The area between the limiting boundaries described in (1) and (2) was filled by a systematic set of usage curves and the coefficients were determined by observation of two existing freeways, i.e., by interviewing the users and comparing with total interzone transfers. The chart was then tested against the Shirley Highway data reported by D.L. Trueblood in HRB Bulletin 61, and was found to

fit relatively well. At least the time-ratio curves fit the California data. In California, whenever a route study involves new location or more than one alternate solution, a complete economic analysis is made, showing user costs for the common set of trips whether made via any one of the proposed alternates or via remaining roads. This work is done in conjunction with the assignment, by punch card machines. The manual coding necessary consists of coding the distance via existing networks for each interzone transfer, and the distance between access points along the line of each freeway alternate. The assignment curves are expressed as a formula for the purpose of machine manipulation.

Books, Documents, Pamphlets, Reports, and Research Projects

1. Motorist Advisories and Traffic Control

Airborne Instruments Lab. FLASH. A.I.L., Deer Park, N.Y. (1971).

FLASH (Flash Lights and Send Help) was designed to test the operational feasibility of cooperative motorists using their headlights to aid distressed motorists. To this end a 55-mile segment of Interstate Highway 4 (I-4) in Florida was selected for an evaluation site.

_____. Means of Locating and Communicating with Disabled Vehicles. A.I.L., Deer Park, New York, (1964), 56 p.

The purpose of this research was to investigate the problem of the disabled vehicle, particularly on limited-access highways, with emphasis on methods of detection and communication.

_____. Reporting of Disabled Vehicles by Cooperative Motorists. A.I.L., Deer Park, New York, (1967).

An experiment has been conducted in four states (New York, Kansas, California and Virginia) to determine whether passing motorists will cooperate by reporting fellow motorists needing help. The passing motorist

was instructed by special roadside signs to report motorists needing help by flashing his headlights at a reporting station where observers recorded motorist responses.

Alexander, G. Development of Information Requirements and Transmission Techniques for Highway Users. Texas Transportation Institute, College Station, (1975), 62 p.

This report is a condensation of a two volume draft prepared by the Airborne Instruments Laboratory on Project 3-12 sponsored by the National Cooperative Highway Research Program. It points to the need for a better communication system for the present and the future. Utilizing a team of men in different fields of study, such as psychology and engineering, the report develops a systems concept and a procedure for its application.

American Association of State Highway Officials. 1964 Proceedings. Washington, D. C. (1964).

This publication includes the following articles:

Funk, John B. "Highway Emergency Communications." AASHO, In Proceedings, 1964. pp. 288-292.

Discusses equipping freeways and vehicles with an emergency signalling device which is capable of instantly informing authorities that an automobile is in trouble at a given location. Also discusses new field of audio-visual signing which warns motorists of exits, accidents, weather conditions, etc.

Kelcey, Guy, and Halstead, William S. "A Multi-Purpose Communications System for Highway Use." AASHO (American Association of State Highway Officials), In Proceedings, 1964, pp. 292-296.

The authors suggest the installation of a specifically designed cable, comprising coaxial and supplementary conductor elements within the right-of-way of a highway, one cable for each direction of traffic flow. To this would be connected appropriate instrumentation and associated facilities so that through the use of a multiplicity of carrier frequencies, a number

of voice, teleprinter, facsimile data transmission, slow-scan television, remote control or other signals may be carried simultaneously. The system, termed "Multicom", can also be interconnected with other communication facilities to expand its usefulness.

Anderson, R. A. and Robertson, R. G. Study and Development of Highway Advisory Information Radio. Atlantic Research Corporation, Missile Systems Division, Costa Mesa, California, FHWA-RD-74-73, December 1974, 265 pp.

A complete highway advisory information radio (HAIR) system was developed for audibily conveying traffic advisory and emergency information to the motoring public using a low power, limited coverage roadside transmitter at dedicated frequencies of 535 KHZ and 1656 KHZ. Types of information conveyed include emergency messages, warning tones indicating the approach of an emergency vehicle, advisory messages to alert motorists of anomalies ahead and alternate routes, and trip needs such as information pertaining to gas, food and lodging services. A major objective of the program was the development of special automotive receivers permitting the motorist to automatically receive the traffic messages while listening to his favorite AM or FM broadcast station. The radio transmission system utilized audio tone codes to achieve control of the automatic receivers; however, the system also permitted message reception with over 95 percent of existing AM automobile radios. Surveys of commercial automobile AM receivers were made to determine tuning range limits and receiving sensitivities at 535 KHZ and 1656 KHZ. It was found that the capability of automobile AM radios to receive out-of-band signals depends almost entirely on field strength and not on the limits of tuning range.

Case, Harry. Research Development of Changeable Message Signs for Freeway Traffic Control. Institute of Transportation and Traffic Engineering, Los Angeles, (1971).

Catholic University of America, Washington D. C. Methodology for Establishing Compliance With New Highway Signs. Funded by Federal Highway Administration. Investigator: Townsend, J. C. Reporting Date: February

1975, Project Start Date: July 19, 1973, active.

The contractor shall conduct a series of experimental studies to determine: (1) information needed for drivers when they make a route diversion decision, (2) feasible methods of diverting drivers other than by visual signs, and (3) factors influencing optimal paths through freeway interchanges.

Dorsch, X, Germany. Changeable Traffic Sign Systems. Funding Agency: Federal Transport Ministry, Germany, Reporting Date: May 1973, Start Date: 1973, active.

Excessive traffic loading of individual sections of road, which is limited in time and by the number of roads overloaded, can often be eliminated or avoided more effectively by traffic engineering methods than by road construction investments. The changeable traffic sign system is one of these methods. The technical expense incurred and the relatively high costs of the construction and operation of this type of facility require detailed economic study. Studies have to be carried out to determine the savings which can be obtained by such systems, in that on the one hand additional traffic space is not required and on the other hand economic losses are avoided by increased road safety and the elimination of traffic jams. Moreover for influencing traffic over the road network the operational costs and costs of the time of vehicles on the normal and alternative sections of road have to be established. The frequency of use and permanence of changeable traffic signs is of significant influence on their economic use. Within the framework of the research project the economic losses due to traffic jams or to the increases in journey time associated with them are to be clarified, together with the extent to which the economic losses caused by diversions can be reduced if account is taken of the losses which occur on the alternative routes. Moreover the traffic jams which can still be represented economically before diversion measures are adopted have to be established. Finally there is to be a clarification of the economic benefit which can be expected from the lower accident figures which are a result of the traffic measures introduced. The final aim is to develop optimization criteria or an optimization method for the installation of changeable traffic sign systems.

Federal Institute Road Research, Germany. Alternate-Route Signs in Connection with a New Direction-Indicating System for Motorways. Funding by Federal Transport Ministry, Reporting Date: May 1972, Start Date: 1972, active.

The Federal Institute for Road Research is studying a new fixed-message indicating system for the Autobahn Network. In addition, the technical and economic limits of a supplementary system will be determined, which in the event of congestion will divert the traffic to links with available capacity. The duration and frequency of saturation conditions and the traffic distribution under various conditions of traffic density will be determined from known survey data, and recommendations for the suitable location of detection and communication devices will be drawn up. It is intended to study the following problems: (1) the extent to which partial diversion is possible according to known traffic flow charts, (2) intervals between the time congestion occurs and the time the diversion becomes effective, (3) the extent to which a large-scale diversion to alternate routes is reasonable in respect to the time and distance, and (4) the economic conditions to be specified for an alternate-route indicating system.

_____. Use of Permanently Fit Signs for Assigning Traffic to Lanes. Funding Agency - Federal Transport Ministry, Germany, Reporting Date - May 1973, Start Date - 1973, active.

According to the West German Highway Code, it is possible to guide traffic on highways by means of mobile or fixed permanently lit signs and thus to attain a certain flexibility. As a preliminary investigation the following points are to be clarified by means of concrete examples: (1) whether the use of permanently lit signs is appropriate for the closing of traffic lanes (e.g. for traffic control at construction sites); (2) whether at sections where a particularly large number of accidents occur, or sections with periodically high traffic volumes in one direction, the diversion of traffic onto lanes of the opposite traffic direction, or to reserved lanes, or onto parking lanes is possible for reasons of safety and economic efficiency; and (3) whether permanently lit signs can be justified for the diversion of highway traffic and for simplifying the access of heavy volumes of traffic diverted onto a highway.

Highway Research Board. Communications and Emergency Services. Highway Research Record 358, (1971).

The four papers, 3 discussions, and 2 abridged papers reflect the concern to operating authorities of rural and urban freeway systems of the standard motorist and present research findings that engineers, administrators and enforcement officials will find useful in dealing with this serious problem area.

This publication includes the following articles:

Dudeck, Conrad L., Friebele, John D. and Loutzenheiser, Roy C. "Evaluation of Commercial Radio for Real-Time Driver Communications on Urban Freeways." Highway Research Record, 358, 1971, pp. 17-25.

Authors studied the problem of communication to rather than from the motorist. They evaluated driver attitudes toward presentation of real-time traffic information by commercial radio, and they concluded that it could play a vital role in an effective urban freeway communication system.

Goolsby, Merrill E, and McCasland, William R. "Use of An Emergency Call-Box System on An Urban Freeway". Highway Research Record, 358, 1971, pp. 1-7.

This is a report on experience with a push-button call-box system installed on an 11-mile section of I-45 in Houston. Four types of assistance can be requested and data for a 6-month period showed that two-thirds of the disabled motorists failed to use the system either because they were not aware of its existence or because they were fearful of the cost involved. One-third of the calling motorists were classed as being gone on arrival.

Sakashita, Masami, Lu, Chyi Kang and May, Adolph D. "Evaluation of Freeway Emergency Service Systems Using A Simulation Model". Highway Research Record 358, 1971, pp. 29-45.

The authors developed a simulation model of an emergency service system (police, mechanical, communication services) for responding to freeway indicents in order to analyze 35 different candidate systems. Costs and effectiveness measures were developed and discussed and

conclusions were drawn regarding the most promising systems. The model can be expanded to include factors not studied in the paper and can be applied to other locations as well.

Highway Research Board. The Changeable-Message Concept of Traffic Control. Highway Research Record 129 (1971).

The application of the changeable-message concept to highway-signing technology permits engineers to exercise more flexibility in providing information, warning, and regulatory messages to motorists as conditions change. Recognizing the value of this evolutionary concept and the need for an open discussion of the relative merits of the several current designs for changeable-message signs, the Highway Research Board Committee on Traffic Control Devices sponsored a conference in July 1971, that brought together those involved in research, development, manufacture, marketing, and operation of the various types of changeable-message signs. One of the objectives of the conference was to publish the proceedings and this report contains the conference presentations. The application of this information should prove highly beneficial to those concerned with more effectively communicating highway and traffic conditions to motorists on an accurate and timely basis. Some of the presentations included in this special report are:

"Some Principles for Communicating with Drivers Through the Use of Variable-Message Displays," by B.W. Stephens.

"Changeable-Message Signs in Ohio," by E. N. Burns

"Potential Use of Variable-Message Signs in New York City," by E. Vinson Hoddinott

"Use of Changeable-Message Signs by Port Authority," by Louis E. Bender

"Fog Detectors for Controlling Changeable-Message Signs," by Edward D. Spear

"Research Development of the Changeable-Message Concept for Freeway Traffic Control," by Slade Hulbert and Ginx Beers

"Changeable-Message Signs," by Irwin Hart

"Varicom Traffic Control and Communication System," by Lawrence A. Powers

"Design, Operation, and Utilization of Changeable-Message Signs with Emphasis on the Rotating-Drum Type," by Daniel B. Dunne

"The Distec System: A Sign of Our Times," by William Ross Aiken

"Changeable-Message Displays: Some Design Considerations," by William Brooks & David Nelson

"Newest Cost Breakthrough for Changeable-Message Matrix Signs," by John J. Mauro.

Highway Research Board. Traffic Control and Driver Information. Highway Research Record 366 (1971).

The principal thrust of these studies is in how to make signals, signs, and pavement markings better serve the interests of improved traffic flow and safety. Principal articles of interest deal with driver information needs and a comparison of selected traffic information devices.

This publication includes the following articles:

Adler, Bernard, and Straub, Arthur L. "Legibility and Brightness in Sign Design." Highway Research Record 366, 1971, pp.37-47.

The authors concerned themselves with sign letter height considerations necessary to satisfy night legibility requirements. They concluded that required letter heights must exceed 55 ft. per-in. rule in order to give good night legibility. They also feel that brightness can vary greatly because of a number of variables and that each sign should be treated individually as a separate design problem.

Allen T., Lunenfeld, H. and Alexander, G. J. "Driver Information Needs." Highway Research Record 366, 1971, pp. 152-115.

The driving task was analyzed to determine the nature and interrelationship of the subtasks the driver performs and the information needed to

perform them safely and efficiently. Data were developed using a modified information-decision-action task analysis method applied to several long driving trips.

Hoff, Gerald C. "A Comparison of Selected Traffic Information Devices." Highway Research Record 366, 1971, pp.116-129.

This study evaluates various traffic information devices with respect to their preference rating by drivers and to the response to each device. The 6 alternates that were offered to the respondents for preference rating were symbolic expressway map sign with colored arrows showing traffic conditions, symbolic expressway and arterial street map sign with colored arrows showing traffic conditions, changeable-message lamp matrix sign, roadside radio transmitter, commercial radio traffic broadcast, and experience and driving background.

Institute of Transport Research. The Application of Automation to Dense Traffic. The Case of Meshed Networks in Urban Zones. Investigator: Fillipi. Reporting date: May, 1973. Start Date: July 1975.

A study of urban traffic control problems, especially traffic congestion is proposed. It will include (1) the methods of preventing congestion in one zone; including anticipated detection of congestion lists in a zone and possible methods of diverting traffic outside the zone; (2) control methods applicable to congested networks.

Institute of Transport Research, Fr. Variable Traffic Signs. Investigator: Verdier, R. Funding by - Institute of Transport Research, France, Research Date - May 1973; Start Date - Jan. 1973. Estimated Completion date - Jan. 1973, Active.

There exist, at the present time, several different French or foreign models of variable traffic signs used in route diversion traffic control operations. Some are more satisfactory than others. The aim of this research is to conduct a comparative study of the various operational characteristics of these traffic signs, in particular, to verify their durability and their satisfactory operation under limit temperature conditions.

Kahn, D. Lane Blockage Effects on Freeway Traffic Flow. Transportation Systems Center, Cambridge, Mass. (1974).

The traffic density buildup following lane blockage on a four-lane freeway carrying low-density traffic is determioned for several different densities characterizing the freeway.

King, G., and Lunenfeld, H. Development of Information Requirements & Transmission Techniques for Highway Users. National Cooperative Highway Research Program, Washington (1971) 239 p.

The objective of the over-all research problem was development of a well-defined information system for the highway user that will represent all conditions which the driver is routinely, occasionally, and rarely confronted. This research defines and measures, where possible, all pertinent factors and functions of the information system. With regard to the highway user, the research includes those parameters that motivate the driver to respond naturally and safely to the range of messages transmitted and attempts to identify the capacity of drivers to assimilate varying amounts of information.

Knoll, Franfurt, Germany. Criteria for Directional and Diversion Systems. Funding Agency - Federal Transport Ministry, Germ. Research Date - May 1972, Start Date - 1972 - Active.

Diversion of traffic to alternate routes sometimes entails sending drivers in a direction opposite to the one in which they desire to travel. In order to allow this diverted traffic to flow safely and without obstruction, a new system of road signs which is consistent for all traffic situations is to be developed. The rerouting sign system is to be supplemented by additional traffic signs in such a way that there will be no doubt in the minds of diverted road users and that the high-cost traffic sign system will be economically justifiable. In the course of the research, the conditions for large-scale diversions in respect to extent, characteristics of sections, and traffic on the network will be verified. Also, to identify the diversions, suitable traffic and direction

signs will be developed for individual junctions, parts of the network, and road sections.

Lu, Chyi Kang. Systems for Responding to Freeway Accidents. Highway Research Record 53 (1971).

The first part of this report contains mainly an annotated bibliography of 196 literature references related to the project. The annotations of the first 149 references are based on a working paper "Literature Research and Annotated Bibliography" prepared for this project by Gopal P. Agarwal of the Operations Research Center in 1968. The remaining portion is added as a result of the continuing research through January 1975.

Maryland University, College Park, Md. Research on Route Diversion Parameters. Investigator: Hall, J. W. Funding Agency: Maryland Dept. of Transportation, Federal Hwy Admin, Wash., D. C. Reporting date: Dec. 1974, Start date: Jan. 1973.

This study seeks to develop sound options for accomplishing route diversion in terms of viable combinations of traffic behavior criteria, the date requirements necessary for such decisions and the types of route diversion communication and control systems to be employed. While the study is exploratory in nature, it is focusing on those factors related to the application of route diversion principles to highway practice.

Moskowitz, Karl. Analysis and Projection of Research on Traffic Surveillance, Communications, and Control. Highway Research Record 84, 48 p.

The objective of the research was to evaluate the state-of-the art of traffic surveillance, communication, and control, and to set forth guidelines for the determination of rapid payoff research that could be undertaken through NCHRP and the state highway departments. The research includes an analysis of ongoing traffic operations research in the United States and abroad. In addition, a listing of traffic operations research needs is presented, together with a gross estimate of the funding requirements.

National Cooperative Highway Research Program. Motorist Aid Systems. N.C.H.R.P., Washington (1971) 28 p.

The Highway Research Board in this report provides information on the motorists' needs, reviews existing and proposed aid systems that offer insight as to how best to furnish the required aid, presents factors to be considered in planning and design, and places motorist aid in the context of the total communications and management systems necessary to provide an efficient highway system.

New Mexico State University. Requirements and Methodologies for Evaluation of the Wayside Communication Link. New Mexico State University, Los Cruces (1969) 68 p.

This is the final report covering work under Contract No. DOT-FR-9-5526 for the Office of High Speed Ground Transportation. This Contract provides for two phases. The first is to determine a set of technical requirements for a Wayside communications link, and the second is to develop a methodology for selections of the best of the proposed communications media.

Renner, John J. A Motorist Radio Service. Advanced Technology Systems, Inc., Arlington, Va., prepared for: Federal Highway Administration. (1972).

The objective of this project was to establish the basis for the promulgation of Federal Communications Rules and Regulations governing a Motorist Radio Service. Such service was to provide a motorist the means for immediately obtaining information pertinent to driving conditions and for obtaining assistance from other motorists or from organizations that provide highway services. It would also provide a means for no-delay reporting of information between motorist and highway authorities for transmission of automatic road-hazard warning, and for automatic location of a communicating vehicle. This service would thus provide for rapid detection and automatic location of vehicle emergencies.

Traffic Engineer Institute, Stuttgart Tech U., Germany. Control Models for Traffic Flow Control With the Aid of Alternative Route Indicators. Investigators: Steirwald, Heusch, Boesefeld. Funding by: Federal Transport Ministry, Germany. Research Date - May 1972, Start Date - 1972.

The results of traffic observations and data logging will be used to set up an experimental control model for automatic guidance. The traffic structure in a part of the autobahn network will be evaluated from the surveys and from travel distances. Development of control criteria and simulation of traffic flow through control models will be used to select parameters suitable for automatic control.

Transport & Road Research Lab., U. K. Weather Surveillance on Motorways. Investigators: Young, C. P., Mace, D. G., Fulbrook, A. Reporting Date: May 1973, Start Date: 1971, Completion Date: 1976, Active.

Highways in the U.K. are being equipped with a computer controlled communications system which will have the capacity to interrogate various sensors. Trials will be carried out to link weather measuring sensors to the communications system, so that information about current road conditions and possible trends can be relayed by telex messages to local weather forecasting offices and other interested bodies. The object of the trials is to improve the forecasting of weather hazards.

Reports issued:

"Weather Forecasting for the Prevention of Icy Roads in the U.K.," J. S. Hay and C. P. Young, Symposium of Weather Forecasting for Industries, 1971.

Transportation Research Board. Better Use of Existing Transportation Facilities. Proceedings of the Seventh Meeting of the Transportation Research Board in Cooperation with the Florida Dept. of Transportation, August 5-7, 1974, Jacksonville, Fla. National Research Council, Special Report 153, Wash., D.C., (1975) 255p.

The Special Report contains papers presented at the Seventh Summer Meeting of the Transportation Research Board. The objective was to present

timely and useful information on the theme of the meeting, Better Use of Existing Transportation Facilities. This publication includes the following articles:

Dudeck, Conard L. "Better Management of Traffic Incidents." In Better Use of Existing Transportation Facilities, Proceedings, Transportation Research Board, National Research Council, Washington, D.C. Special Report 153, 1975, pp. 116-122.

The author delineates the nature and scope of the problem of the need for better methods for detection and management of freeway traffic incidents and gives several challenges still to be met by research and implementation in arriving at effective incident management.

McCasland, William R. "Experience in Handling Freeway Corridor Incidents in Houston." pp. 145-155.

McCasland tells of Houston's incident detection and response capability and points out that although the program is effective, it could be improved by better coordination and further commitments of resources by the agencies involved.

McCasland, William R. "Review of Research on Controlling the Level of Service on Urban Freeways." In Better Use of Existing Transportation Facilities, Proceedings, Transportation Research Board, National Research Council, Washington, D.C., Special Report 153, 1975, pp. 26-31.

The author summarizes Texas experience with improving and controlling the level of service on freeways and describes methods such as geometric roadway improvement, detection and management of incidents, and improvement in passenger-vehicle ratios.

McDermott, Joseph M. "Incident Surveillance and Control on Chicago-Area Freeways." pp. 123-145.

Extensive operating experience is the basis for this report of surveillance and control for incident detection and management on Chicago's high volume expressway system.

Meister, Elmo. C. "Advance Planning for Emergency Handling of Highway Traffic." In Better Use of Existing Transportation Facilities, Proceedings, Transportation Research Board, National Research Council, Wash., D.C., Special Report, 153, 1975, pp. 111-115.

Procedures for handling emergencies cannot be completely preplanned but general guidelines can be prescribed and crews trained to handle emergencies before they occur. The author describes the California process and reports on actual case studies where the plans were tested.

Roper, David H., Murphy, Richard J., and Zimowski, Robert F. "Alternate Route Planning: Successful Incident Traffic Management." pp. 141-144.

California experience with development and implementation of alternate route schemes has led to a procedure of preplanning for required capability when incidents cause closure of freeways. The authors make a strong case to support this systems approach.

Yagoda, H. Nathan, and Adler, Bernard. "System Challenges of Traffic Incident Management." p. 156-165.

Yagoda and Adler concentrate on the system challenges of incident management programs and points out that such programs can no longer be left to chance in the face of today's urgent need to derive maximum benefit from existing facilities.

White, Frederick. Lane Control Studies. Texas Transportation Institute, College Station (1971).

Annotated Bibliography on lane control studies. Contains 38 entries and is, as described in foreword, selective and not meant to be comprehensive.

2. Police and Road Service Patrols

Automotive Safety Foundation. Maryland's Highway Safety Needs in Police Traffic Services. ASF, Washington (1969).

This is one of 12 technical reports on government functions in Maryland relating to highway traffic safety, resulting from a study project under a contract agreement between Maryland State Roads Commission, acting for the State, and the Automative Safety Foundation. The objective of the police traffic services portion of the Maryland study is to assist the State in developing a comprehensive statewide police services program.

Fennessey, E. F., and H. C. Joksch. Police Traffic Services and Road Safety. Hartford, Conn., The Travelers Research Center, Inc. (1968) 156 p.

The specific purposes of this report are to: 1) assemble all available studies that have scientifically attempted to measure the relationship of police services to highway safety and accident reduction; 2) critically evaluate these studies; and, 3) develop research recommendations that would lead to an improved understanding of their relationship. A discussion and description of the scope, objectives and functions of police activities in the motor vehicle transportation system is included to provide a contextual framework in which to examine the results of the quantitative literature review presented here.

National Proving Ground for Freeway Surveillance. Control and Electronic Traffic Aids. U. S. Bureau of Public Roads, (1965) 19 p.

The purpose of this study was to determine if the time from occurrence of an incident which blocked a traffic lane or lanes to the time when the incident was aided by police or wrecker was decreased due to television surveillance and direct line communication with the police department and towing service. The type of aid given to an incident as a result of communication with the police or wrecker was also studied.

International Association of Chiefs of Police. Smith, R. Dean, and Espie, David A. Guidelines for Police Services on Controlled Access Roadways. International

Association of Chiefs of Police, Washington (1968).

This report presents the findings and conclusions of a three-year study of police operations on controlled access highways in the United States. The purpose was to: 1) examine in detail the operational and administrative processes of police systems servicing controlled access roadways and 2) to develop guidelines for policy making and ultimately, decision making at all levels in the systems.

U. S. Bureau of Public Roads. Police Functions in Highway Traffic Regulation in an Emergency. USBPR (1967).

Traffic supervision has always been a basic responsibility of various police agencies and so a call for police traffic services, even in unusual emergencies, generally is classed as routine. However, emergency highway traffic regulations poses unique problems and responsibilities for police as it does for all those charged with official obligations.

3. Traffic Flows and Delays

Angello, Richard J. Measuring Time Losses at Highway Bottlenecks and Empirical Findings for the Chesapeake Bay Bridge. HRB No. 467 (1973) 65p.

Provides a technique for estimating delay time at highway construction and compares with empirical data gathered at bridge site.

Federal Highway Administration, Wash., D.C. A Guide for Highway Traffic Regulation in an Emergency. July 1, 1974, 8 fig., Tabs, 11 App.

The nature, scope and operation of emergency highway traffic regulation (EHTR) is discussed in this guide which was designed to help the states prepare plans which would work effectively, both individually and collectively. It will also serve as a tool to aid in the updating of the state's plan through the publication of changing national policies and programs. The general background of the EHTR is reviewed. The broad fields

of civil emergency planning and natural disaster are briefly discussed. The organizations involved in emergency planning and in EHTR operations are reviewed. The functions, personnel, equipment and communications in EHTR operations, as well as aspects such as regulated routes, road-use permits and EHTR signs are also covered. The role of the military, and nuclear radiation hazards to highway transportation are considered.

Goolsby, M. E. Accident Reporting and Clearance Procedures on the Gulf Freeway. Texas Transportation Institute. Res. Rept. No. 139-1, Sept., 1969, 14p., 15 fig.

A research project on freeway control and information systems resulted in this study of the formulation and evaluation of procedures for the clearing of disabled vehicles from the freeway. There are two general causes of congestion at a reduced capacity scene: (1) the physical blockage of traffic lanes, and (2) the distraction of the motorists created by the activity around an accident. The problem discussed is the removal of a police unit. The effect on traffic flow of two situations was determined: (1) an accident blocking one traffic lane, and (2) vehicles involved in an accident parked on the freeway shoulder. Traffic flow data collected at the accident scene shows the average flow was 45.3 vehicles per minute or 49 percent of normal flow. The removal of the accident at the freeway shoulder resulted in a flow of 72.8 vehicles per minute, only 78 percent of normal flow. Significant traffic flow and safety programs can be realized by police implementation of policies and procedures which expedite the removal of disabled vehicles from freeways. Further benefits can be gained by removing the vehicles to a location screened from the view of freeway drivers. Any policy which can reduce the time required for detection of an accident, dispatch and travel of police, and accident clearance from the freeway, will achieve substantial gains in motorists' benefits.

Hall, J. W. Research on Route Diversion Parameters. Maryland Univ. College Park, Md. Creighton, Hamburg Incorporated, Delmar, N.Y. Maryland Dept. of Transportation, Brooklandville, Md., Final Rept; Dec. 1974, 134 p.

The study seeks to determine the feasibility of the real-time diversion of traffic in an intercity corridor. Using the 35 mile corridor between Baltimore, Md. and Washington, D.C. as a study area, efforts focused on highway operation, incident detection, diversion policy and communication techniques. Because of the general lack of information of diversion signing techniques, a questionnaire study of 6655 motorists using the corridor was undertaken. Motorists preferred signs presenting information on the length of congestion, congestion cause with exit instructions or the availability of suitable alternate routes. It is felt that if the growth in the Baltimore-Washington corridor traffic continues, a real-time diversion program would be warranted in about ten years.

Herstien, H. I., Yagoda, N. H., Orman, J. M. Minicomputers in Network Traffic Control. Traffic Engineering & Control, U.K.

The first network traffic control system based on a minicomputer made its appearance in North America in the central business district of Albany, New York. The system controls 25 key intersections and its capabilities include: on-line or off-line optimization of signal timing, on-line adjustment of the timing paameters based on real-time detector inputs, fire apparatus emergency pre-emption and preferential routing, and inputs to reflect weather conditions and holidays into the operating scheme.

Sperry Systems Management Div. - Funded by Federal Highways Admin. Diversion of Inter-city Traffic at a Single Point. Investigator: Gordon. Reporting date: April 1974, est. completion date: Dec. 1974 - (Active).

The purpose of this project is to develop requirements for a real-time alternate routing system by establishing a "test bed" system for experimentation, in cooperation with the Maryland State Highway Administration.

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